The impact of physical preparation on clubhead speed in youth golf

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ABSTRACT

Over recent years, the emphasis placed on the physical preparation of golfers has drastically increased. Players now hit the ball farther, courses have become longer, and the relationships between driving distance and golf score have become more prominent. Recent literature has identified strong relationships between strength and explosive strength characteristics with golf performance. Both warm-up and training interventions have shown positive impacts on golf performance in adult golfers. As a result, many junior golf programmes have also begun to implement strength and conditioning support. However, research into the impacts of warm-up, the relationships between physical characteristics associated with higher performance and impact of training on youth golf performance is minimal. The purpose of this thesis was, therefore, to assimilate the background golf strength and conditioning literature, establish the impact of warm-up on youth golf clubhead speed (CHS) and perceived shot quality, identify physical characteristics which relate to youth golf CHS and establish the impact of resistance training on youth golf CHS and ball speed (BS).

Findings from three systematic reviews led to subsequent interventional and cross-sectional research. These investigations examined the topics outlined in the research purpose. Throughout the process, existing literature as well as experiment helped to identify golf performance and physical dependent variables which the warm-up and resistance training interventions were designed to enhance. Strength and conditioning practitioners were kept in mind when designing experimental chapters. Warm-ups were, therefore, time-efficient using minimal equipment and resistance training interventions demonstrated positive effects

with realistic dose frequencies. This thesis was thereby able to demonstrate value in encouraging youth golfers to engage in a warm-up and resistance training for CHS and BS enhancement as well as for improvements in perceived shot quality. Resulting in practically appropriate interventions to support in this goal. Due to the relative infancy of work in this area, this thesis offers numerous specific suggestions for future research throughout.

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Speaking engagements/other dissemination

Invited speaker: Physical Preparation of the Golf Athlete. BASEM 'Walk 500 miles'. 2014

Invited speaker: Numerous topics. England Golf National Coaching Conference. 2013-2017

Invited course lead: Physical Preparation of the Golf Athlete. 2-day workshop. European Tour Performance Institute CPD. 2017

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LIST OF ABBREVIATIONS

CHS	Clubhead speed
CMJ	Countermovement jump
HCP	Handicap
ICC	Intraclass correlation coefficient
MDC	Minimal detectable change
PEDro	Physiotherapy Evidence Database
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
RM	Repetition maximum
RMBT	Rotational medicine ball throw
RMBTL	Rotational medicine ball throw to the left
RMBTR	Rotational medicine ball throw to the right
SLJ	Standing long jump
SMBT	Seated medicine ball throw
SMBTL	Seated medicine ball throw to the left
SMBTR	Seated medicine ball throw to the right

PART ONE: INTRODUCTION AND BACKGROUND

"There's no way you can get away with not being an athlete these days. You have to be working out in the gym, otherwise, someone else is…Someone else then has a whole set of skills that you don't have. So there's no doubt, to be the best player in the world, you have to be an athlete"

Justin Rose

1 CHAPTER ONE: GENERAL INTRODUCTION

1.1 PREFACE

Golf is often considered a technical sport from which skill and strategy are core components;[1] however, recently we have seen an increased appreciation of the physical demands of the game. This heightened awareness has drawn focus towards strength and conditioning.[2] The game of golf has gone through an evolution, becoming more explosive, with longer courses, resulting in an increased emphasis on driving distance and power. As a result, we see many elite players becoming more physically aware and prepared than ever before. Golfers place great importance upon maximal yet accurate displacement of the ball, which is achieved through attaining a high clubhead speed (CHS), and this has a strong relationship with golfing score.[2-4] Thus, professionals and amateurs are often in search of methods to increase their CHS.

Moreover, a golfer has substantial forces placed upon them during the full swing,[4] and overuse injuries are common.[5] As such, golfers are likely to require the requisite physical qualities to tolerate the growing forces applied to their bodies during the swing and minimise injury risk.[6]

The importance of strength and conditioning, as well as other components of physical preparation, are now essential within modern golfers' routines. Educating players in the early stage of their development is important, in order to develop the necessary knowledge, understanding and positive behaviours in this critical area. As a result, youth golf programmes commonly integrate components of strength and conditioning into their offering. Youth national performance programmes, whose measurement and funding are often performance orientated, are not only looking to use strength and conditioning practices to support longer-term development players but also extract high-level performance in short to mid-term. Despite this, specific research into the impact of strength and conditioning across youth golf populations remains limited. This thesis concentrates on developing the currently inadequate knowledge base surrounding the effectiveness of physical preparation of youth golfers.

Warm-up practices in young players, and their effects on youth golf performance are poorly understood. However, research demonstrates the effectiveness of warm-up in adult golf populations.[7-10] Moreover, across youth sport, warm-ups have been shown to improve performance, [11-13] and reduce injury risk.[14] Integration of these practices early in an athlete's journey may also be important in developing the desirable warm-up behaviours through to adulthood. As a result, this thesis will investigate the effectiveness of warm-up on youth golf populations.

Despite an insufficient understanding of the effects of resistance training on youth golf performance, there is a relative abundance of research across the wider youth literature.[15-17] As such, incorporating resistance training into youth athlete's schedules seems to be an essential component of their development, which will both enhance physical performance[18,19] and mitigate injury risk[20,21] across sports. Research has shown performance improvements occur in power and strength measures,[18,19] which are qualities likely to be of value to golfers. These findings certainly indicate the potential for resistance training to positively influence golf performance. This thesis will identify desirable physical characteristics associated with performance in order to design and test appropriate training interventions. The effectiveness of resistance training targeted towards enhancing those physical and performance characteristics will also be tested, leading to applied suggestions to the wider community of practice.

1.2 Thesis Statement

This thesis states that *physical preparation is an essential component of a youth golfer's development.* Youth golfers should, therefore, *complete a warm-up* and *engage in resistance training* to improve perceived shot quality, CHS and BS. As such, the conjectures set forth through this thesis are two-fold:

1) All youth golfers should *complete a warm-up* to support their performance goals. Warm-ups can be completed in a short period, using no additional equipment and can improve clubhead speed and driving distance as well as shot quality, which will lead to higher levels of performance.

2) All youth golfers should *engage in resistance training*, coached by an appropriately qualified professional, in order to support their performance goals. Resistance training only needs to be completed once weekly and will enhance desirable physical qualities, as well as improve clubhead speed, which will lead to higher levels of performance.

I investigate this thesis statement through the research purpose and research questions outlined in sections 1.6 and 1.7.

1.3 MOTIVATION

The factors outlined below motivated me to write this thesis, which spans both performance sport and strength and conditioning research and practice. Together, these motivations necessitate the advancement of youth strength and conditioning research in golf.

1.3.1 The rise of strength and conditioning in youth sport

With 94% of all UK 11-15 year old's taking part in sport and over 76% involving themselves competitively,[22] sport is a critical societal construct. Young people are not only encouraged to engage in healthy behaviours through sports participation, but it can also become an essential aspect of a child's social structure and identity. Many young people participate in resistance training for enjoyment, but young athletes also use it as a means of enhancing their sports performance and chances of future success. Many drivers can sit behind a young athletes desire to achieve in their sport, but there are undoubtedly considerable opportunities for those who excel. Young athletes are not only able to elevate their status among peers and society but can gain sponsorships, opportunities to travel and compete internationally, secure lucrative university and college scholarships, as well as pursue financially rewarding careers as they progress into professional ranks. Many national governing bodies and other sports organisations are willing to invest in this success, with funding often partly dependent on youth performances as well as hopes for developing and securing future stars. As a result, the potential success of a young athlete will stimulate investment in and openness towards enhancing sports performance through increasing of resources and support. The targeted use of sports science and physical preparation in youth sport is therefore growing, and with it, strength and conditioning provision and practice. Academies, national governing bodies, schools and colleges as well as other sports organisations are frequently employing strength and conditioning coaches and sports scientists to support their athletes and improve performances. We cannot overlook the rise in strength and conditioning within and professionalism of youth sport.

1.3.2 Importance of warm-up across youth sport

With the growth in sports science and strength and conditioning support across all levels of sport, warming up has become a well-recognised method of short-term performance enhancement as well as a successful injury risk reduction strategy.[23] Consequently, warm-up activities in both youth and adult sport are common. We frequently observe warm-ups being undertaken by athletes participating in many sports events, from sprinting to cycling and football to rugby, with substantial evidence supporting these use cases.[23] While some warm-up approaches can involve expensive equipment and bespoke facilities,[9] they can also be time efficient, accessible and use minimal equipment.[7] As such, athletes can enjoy improvements in performance and reductions in injury risk across all levels of sport. However, there is a lack of research concerning the implications of warm-up in youth golf, and practices are often suboptimal. While we are likely to see a structured team warm-up at a local under 16s football tournament, this may not be the case at an under 16s national-level golf event. With this in mind, in this thesis, I test the effectiveness of a simple golf warm-up on youth golf CHS and perceived shot quality.

1.3.3 Knowledge advances in youth resistance training

With the rise of strength and conditioning practices in youth sport, athletes are not only improving their warm-up practice but are also regularly engaging in resistance training. In youth populations, attitudes, as well as behaviours surrounding resistance training are evolving. Research has consistently demonstrated a multitude of health benefits on offer, alleviating outdated concerns around associated risks,[15-17] and providing wide-ranging evidence supporting its use in young athletes.[15-17] Consequently, national governing bodies and other sports organisations often support early involvement in resistance training, and supply coaches and facilities to allow for full engagement. As with warm-up, we see involvement in resistance training across a wide array of sports, and the likelihood of an athlete's early exposure is increasing. With growing positive attitudes, behaviours and bodies of research supporting resistance training in youth athletic populations, it is ever important that golf is not left behind.

1.3.4 The practice-research gap in youth golf

Outlined in the previous motivations for this thesis, the evolution of strength and conditioning practices across a broad spectrum of youth sports are a reality. However, the golf literature does not offer support or information as to how coaches, governing bodies and golf teams should be engaging in strength and conditioning through youth development. Conversely, well-informed strength and conditioning professionals are certainly not about to wait for research papers to immerge before starting to engage young golfers. Instead, they lean on the broader bodies of research and their own experiences, alongside working with player expectations, employing an evidence-based practice approach,[24] but accepting the limitations of their knowledge. While undoubtedly defensible, this approach inevitably leads to assumptions within professional practice which may or may not be correct, as well as leaving the coaches exposed to cynicism and players to sub-optimal support. The overarching motivation for this thesis is to address the practice-research gap by providing evidence which furthers knowledge to support and evolve coaching decisions and practices in youth golf.

1.4 Research Philosophy - Pragmatism

Throughout this thesis I adopt a pragmatic research approach, which acts as a guide for decision-making at various stages of study design and execution. This approach fits well with the motivations of the thesis, especially in regard to addressing 'the practice-research gap in youth golf'. Within this context, a pragmatic approach is supported by Glasgow[25], who highlights that a slow and uncertain translation of research into practice could well be, in part, due to the frequent overemphasis of science theory and explanatory models as opposed to pragmatic research. Pragmatism is a philosophical approach which evaluates theories or beliefs based on the success of their practical application. This approach therefore emphasises the importance of knowledge translating to a difference in action, and warns against the excessively idealistic and abstract.[26] In a research context, this will require the creation of applied/practically applicable research questions, which are subsequently approached in a way which allow for results to be of potential use in practice.[27]

Pragmatism in research is not necessarily faithful to one philosophical system or notion of reality but places the problem at the center of research enquiry. Study design, data collection and analysis methods are constructed while considering their likelihood of providing insights to the problem in question with no loyalty to a particular research paradigm.[28] With this in mind, methods and theories used should be based on their potential usefulness in answering practical problems, as opposed to exploring the truths of nature and reality.[27]

Glasgow[25] goes on to summarise key characteristics of a pragmatic approach, and suggests factors for consideration, including; addressing specific practice needs with focus on application, context and usefulness; keeping models and frameworks relatively simple with focus on relationships, context and key issues for success; using designs which address issues of practitioners, policy makers (key stakeholders) and patients (athletes) with focus on resources, context, replication and applicability of results; using measures which are feasible and actionable in real world settings which are brief, broadly applicable and sensitive to change. Pragmatism in research should therefore be judged on its ability to be useful, workable and practically applicable[29] and ultimately whether it yields change in practice.[30]

1.5 APPROACHES TO PERFORMANCE MEASUREMENT IN GOLF

There are a great many issues in quantifying 'golf performance', especially when trying to attribute changes in performance to the enhancement or decline of a specific physiological, psychological, technical, tactical, social or environmental state. At first glance, it may seem like a fairly simple task, and for the purposes of a golf tournament or professional tour it is. The most important measure for a golfer is their scoring average at the event or over a season. For the high-level amateur, an amateur world ranking is also of importance. For the professional, a world ranking, tour standing, and prize money earnt are further performance indicators. However, there are many variables which can impact upon these macro level performance outcomes. The meso and micro statistics from the game are vast. At a meso level, statistics can be broadly broken into measures off the tee, approaching the green, around the green, putting and overall scoring. Each measure will have a further group of sub-categories which contribute to the whole. Taking the example of off the tee statistics, the following (non-exhaustive) list is considered important;[31] strokes gained off-the-tee, strokes gained tee-to-green, driving distance, percentage of yardage covered by tee shots, percentage of yardage covered by tee shots on par 5s, driving accuracy, tendencies for rough (and then rough to the left and right), tendencies for bunkers (and then bunkers to the left and right), fairways hit and missed, general left and right tendencies, distance control and ball striking. Each measure is then impacted on by a number of micro level metrics such as; clubhead speed, ball speed, smash factor, launch angle, spin rate, distance to apex, apex height, hang time, carry distance, carry efficiency, total distance efficiency among others. These are in-turn affected by many additional factors, including; course layout (courses are specifically set up to force players into a range of highly variable challenges), course conditions, equipment, player skill level and technical proficiency, tactical and technical decision making, player psychology, social interactions, and physiological state. Each high-level course, equipment or player related measure above can then be further sub-divided. Taking the example of player physiology, influencing factors of note could include; strength, explosive strength, flexibility etc. but also injury and health, thermoregulatory control, neurological functioning, circadian rhythms among many others).[32] In the case of equipment, influencing factors could include the ball, clubhead mass, shaft length and shaft stiffness among others.

With these factors in mind, understanding the relationships between physical characteristics and ‘golf performance’, or the impact of various physical preparation strategies on ‘golf performance’ is a highly complex and multifaceted endeavor. It is certainly beyond the scope of one PhD, and therefore beyond the scope of this thesis. As such, clear decisions had to be made regarding the potential thesis direction. Decisions were made in-line with the pragmatic research philosophy, and specifically the suggestions by Glasgow[25], calling for research which addresses practice needs, using simple approaches, addressing key areas for success for practitioners, stakeholders and athletes, using feasible measures which were broadly applicable. With this in mind, three potential research directions were considered. I have outlined these with some speculation over their potential place in the physical preparation in golf.

1.5.1 Injury and illness risk reduction

Inherently as clubhead speed increases so does injury risk, as the player has to sustain the increased forces associated with swinging faster. To counter this when we plan to upgrade the engine size, we also need to build a well-balanced chassis. This means increasing the ability of the relevant tissues (i.e. muscles and tendons) and structures (i.e. bones) to tolerate load. This is a potential explanation for the utility of resistance training in golf for injury risk reduction. The force magnitude at the lumbar spine alone is worthy justification for the inclusion of strength training. Forces of ~7500N have been reported from elite players swinging with a driver.[33] It is therefore unsurprising that in a published injury audit from the PGA European Tour the lower back, along with the neck and wrist, were the most prevalent injury sites.[5] The same report showed that 80% of these injuries were related to overuse, which according to a large meta-analysis and systematic review could be reduced substantially through engaging in strength training.[6] Many injury resilience strength exercises may actually be the same as the performance enhancement solutions. By way of example, the deadlift may not only increase leg strength to facilitate longer drives but may also increase the tolerance of the back, trunk and wrist musculature, with particular supporting evidence that it is useful in the rehabilitation of lower back pain.[34] This is a real bonus as it makes for efficient programming. Unfortunately, this is not the case for the neck which is insufficiently exposed in traditional compound strength exercises (i.e. deadlifts), so some additional, isolated neck specific conditioning may recommended, as used in other sports with high rates of neck injury[35].

Improving or maintaining mobility is another side effect of good quality strength training. Contrary to common belief, the lengthening phase of muscle activity in strength training exercises increase muscle length and overall mobility.[36] Like cardio-respiratory and mobility development, strength training offers an array of health-related benefits which are well documented. Indeed, the American College of Sports Medicine (ACSM) now include (twice weekly) strength training as part of their recommendations for general health.[37] Exercise is now often described as a vaccine to illness given its protective effects against an array of both acute and chronic conditions.[37] Injury or illness means time away from practice and given that golf is a highly technical sport this is very likely to have a large negative impact on performance over time. Considering the significance of this, it becomes clear that perhaps a large (albeit indirect) accumulative performance impact could be long-term injury avoidance through physical preparation. Unlike with determinants of performance such as clubhead speed, where we can only suggest improvements may help, it is probably safe to insist that avoiding injury and illness will help performance. If we enable the player to take to the course, range or putting green as often as they like and miss very few practice days or tournaments, this is likely to accumulate into a large positive performance impact. This is a long process and not a sell that is likely to excite a player, but is important, nonetheless.

When considering directions for this thesis, the role of physical preparation in injury avoidance for youth golf was certainly a potential area of study. However, there were a number of practical constraints in exploring this area. These included the need for long-term access to large groups of players for prospective epidemiological research, who were regularly engaging in resistance training for their sport. Alongside this, there is already a strong body of evidence across sport that youth and adult engagement in resistance training will aid injury risk reduction.[6, 16] Also, a catalyst for cultural change, and improved uptake of physical preparation in youth programmes was likely to emanate from the more glamorous demonstration of direct performance enhancement. Which would in turn have potential to increase the likelihood of accessing larger prospective groups for injury research in the future. If direct performance enhancement was possible through resistance training, likelihood of practical uptake would be high, and based on the current available evidence, many youth athletes would inadvertently benefit from the known health and injury benefits.[6, 37] These points made exploration of injury risk less pressing than how to improve performance through resistance training for the purpose of this thesis. However, is an important direction for future research.

1.5.2 Transfer to technical ability

It is commonly accepted that a change in technique is facilitated by a coach, through use of professional judgement and decision making,[38] holistic approaches and structured coaching processes.[39] However, it is perhaps underappreciated how altering a physical capacity (i.e. strength, stability, mobility or control) can over time influence technique. It is important for players and coaches alike to understand that although physical preparation may certainly play an important part in helping a player make a swing change,[40] the gym is not likely to be the best place to rehearse the aspired movement pattern. Rather, the gym could be used to drive changes in physical capacities (identified through a discussion with the swing coach) that may impact on the players ability to make the shapes their coach wants from them.

This is likely to be best achieved with de-contextualised exercises that do not resemble the swing pattern but carry the potential to remove physical barriers that are preventing a player from moving a certain way without loss of posture or compensations. If facilitated correctly, changes in technique could then have a whole host of second order effects on clubhead speed and injury risk, as well as other performance markers. For this reason, transfer to technical ability should not be overlooked, but there is currently little empirical evidence that supports or refutes the transfer to technical skills. The exercises used to impact technical ability will obviously be specific to the individual, but specialist input will be required to identify and implement this. Even then, the true impact on technique is often unpredictable, due to the wide range of impacting factors.

Research into the relationships between and impacts of changing various physical qualities on other golf performance markers through facilitating technical transfer is a worthwhile pursuit. With potential of being more orientated towards various golf performance markers (technical and outcome based), its exploration also addresses some of the issues raised when discussing concerns around injury risk reduction as a thesis direction. While exploring these avenues was of great interest, a range of barriers were faced. In order to fully explore this area, participant eligibility criteria and guidelines would have to remain strict. Participants would not be able to have personalised coaching on their own individual areas of skill development, without compromising the findings of any resistance training interventions. Participants would also have to be of a high-skill level to be relevant to the target population of this thesis (high-level amateur youth golfers). Finding high-level amateur youth golfers and imposing strict personal technical coaching bans over the course of a study seemed unrealistic and ethically questionable. While other, less strict approaches may have been taken, results were likely to be compromised without these criteria being met. Moreover, in order to evaluate technique change, the golfers would need to be measured in biomechanics laboratories with three-dimensional camera systems. Something which I had limited access to, and participants were unlikely to live near. Therefore, restricting the feasibility of these types of investigations. Although the investigation on transfer of physical preparation to technical ability is certainly of great interest and worth of investigation in the future, the empirical studies within this thesis were directed away from this topic.

1.5.3 Clubhead speed

Few golf coaches or analysts would contest the importance of club head speed in modern day golf, research has shown that the faster you swing the club the lower your handicap (r=0.95).[3] Further, even subtle increases are associated with significantly lower scores on par 4 and 5 holes.[41] Therefore, this is one avenue where a gym programme can have a direct performance impact. Indeed, Brodie[42] states that a 20-yard increase in distance off the tee will incur 0.75 strokes gained per round,[42] equating to three shots over a four-day tournament. Clubhead speed is therefore highly likely to impact upon the macro level performance measures, while also being a simple, feasible and important to players, coaches and practitioners.

As with most striking, hitting or throwing sports, the lower body is the engine (force generation) for the motion of the golf swing.[43] This is why leg strength and explosive strength are likely to be a priority. This is now supported by research indicating significant relationships between lower body strength, explosive strength and CHS.[44, 45] Most amateurs (and many professionals) may benefit from increases in driving distance secondary to strength training due to their often 'untapped' strength potential. This may particularly true for youth, female and more senior players who generally speaking are more likely to have lower pre-existing muscle mass and strength levels than their young adult, male counterparts. Once the force has been generated by the lower body, this then needs to be transmitted into the clubhead across the trunk and through the arms in an appropriately sequenced pattern. The trunk should therefore be developed to effectively transmit force, thus enhancing the efficiency of the engine (lower body). As a result, not only is clubhead speed beneficial (for the reasons outlined above), but it is also highly likely to have relevant links to a golfer's physical state.

Of note, in comparison to other performance measures such as handicap, golfing score or even driving distance, clubhead speed will have fewer additional influencing factors when looking to control an experiment within this thesis. This is obviously true for golf score, which will be affected by a range of meso and micro level factors discussed previously. But also, even in the relatively simple case of driving distance, factors related to the centredness of strike, launch angle and spin rate, as well as wind, rain and ball temperature will all influence the final outcome far more than with clubhead speed. Clubhead speed is not without its own set of determining factors from equipment (clubhead mass, shaft length, and shaft stiffness) and the golfer (swing technique, x-factor and x-factor stretch, kinematic sequence, ground reaction forces, wrist mechanics, anthropometrics and movement variability). However, all of these factors are also at play in measures of driving distance as well as meso and macro level outcomes such as tee to green or overall score. Clubhead speed is the first reasonable point where the majority of the influencing factors are related to the golfer's body, and therefore likely to be well linked with physical preparation, while still being a measure of the golfer's influence on their sports equipment and external environment (how they influence their golf club). Through a combination of being performance relevant, likely related to a golfer's physical condition, possible to undertake within the context of my research constraints, of personal interest and of pragmatic value, investigating the impact of physical preparation on clubhead speed in youth golf was the direction I decided to take this thesis.

1.6 Research Purpose

The purpose of this research is to (i) assimilate the background golf strength and conditioning literature, (ii) establish the impact of warm-up on youth golf perceived shot quality and clubhead speed, (iii) identify physical characteristics which relate to youth golf clubhead speed, (vi) establish the impact of resistance training on youth golf clubhead speed and ball speed.

This research will provide strength and conditioning professionals with more information on which to base their practice and allow youth golfers to receive better strength and conditioning support.

1.7 Research Questions

In order to meet the research purpose, I propose the following research questions:

Research Question 1: What is the scope of literature exploring physical preparation of the golfer in areas of warm-up, physical characteristics associated with golf performance and the use of strength and conditioning interventions to enhance performance?

Before being able to identify and appropriately design suitable research studies to investigate physical preparation in golf, it is necessary to understand the current literature in this area. Answering Research Question 1 question will allow for the requisite appreciation of current knowledge in the areas outlined. This will support the identification of suitable knowledge gaps worthy of further exploration. In order to answer Research Question 1, I propose the following research sub-questions:

1) *What is the scope of literature investigating the impacts of warm-up on golf performance?*

2) *What is the scope of literature investigating the relationships between physical characteristics of golfers and golf performance?*

3) *What is the scope of literature investigating the impacts of strength and conditioning on performance?*

(I explore this research question, and the sub-questions over Chapters Two, Three and Four)

Research Question 2: Are clubhead speed and shot quality enhanced through an appropriately designed warm-up in high-level youth golfers?

The next stage of the thesis is to design and implement an empirical study to investigate effects of warm-up on youth golf CHS and perceived shot quality. This study will allow for a better understanding of potential methods for immediate performance impact in youth golf populations.

(I explore this research question in Chapter Five)

Research Question 3: What physical performance measures are most strongly related to clubhead speed in youth golfers?

After an investigation of immediate performance impacts through warm-up, I will explore more long-term strategies for CHS enhancement through physical preparation. In order to design and appropriately administer training to youth golfers, it is first necessary to identify desirable physical characteristics associated with higher performing players. Answering Research Question 3 will allow for more targeted identification of suitable dependent variables as well as offer knowledge to support programme design in future interventional studies.

(I explore this research question in Chapter Six)

Research Question 4: Does resistance training, focused on developing strength and explosive strength, result in greater physical performance, CHS and ball speed (BS) outcomes than no training in youth golfers?

Having identified physical characteristics associated with higher CHS in previous stages, Research Question 4 seeks to understand if enhancement of these desirable qualities, through training, leads to CHS and BS enhancement. Through this question, I hope to understand if we should use resistance training for performance enhancement in youth golf.

(I explore this research question in Chapter Seven)

Research Question 5: Does the addition of a concentric dominant medicine ball throw prescription lead to improved physical performance, CHS and BS outcomes when compared to isometric dominant trunk exercises in an otherwise identical resistance training programme delivered to youth golfers?

If in Research Question 4, resistance training is demonstrated to support CHS and BS enhancement in youth golfers, Research Question 5 will investigate methods of programme optimisation. I will investigate the addition of specific medicine ball exercises within a resistance programme, following from my findings in Research Question 3. This will build on Research Question 4 by offering suggestions to coaches and researchers regarding the relative importance of specific exercise solutions in youth golf. Answering Research Question 5, in combination with Research Question 4 will provide training suggestions which strength and conditioning coaches can employ within their practice.

(I explore this research question in Chapter Eight)

In addition to these broad and high-level research questions, in each chapter, I offer a further outline of research objectives. Each objective is concerned with the necessary process in order to suitably answer the higher-level question and I therefore discuss and conclude each chapter in the context of that answer.

1.8 Overview of Chapters

1.8.1 Part One: Introduction and Background

In this part, I explain the themes and approaches of the thesis. I also examine the background literature through systematic review related to central areas of investigation:

Chapter One: Within this chapter, I present a broad overview and introduction to the thesis, leading to a research purpose and five central research questions.

Chapter Two: In this chapter, I present a systematic review of warm-up and its effects on golf performance. This review provides context to subsequent chapters and supports in my identification of knowledge gaps relating to this area. In this chapter, I also offer a quality assessment of the literature, which alongside the gap analysis provides support towards suggestions for future research. I identify many gaps in the literature and highlight the absence of youth warm-up research in golf.

Chapter Three: In this chapter, I present a systematic review which explores the literature surrounding physical characteristics of golfers and how they relate to performance. In the review, I provide a comprehensive analysis which gives context and support for future chapters. I compile a detailed discussion of areas investigated and areas lacking from the current literature. While identifying a range of further topics for further investigation, I emphasise the absence of literature in youth golf.

Chapter Four: In this chapter, I present a systematic review looking into the impact of resistance training on golf performance. In this review, I offer a detailed discussion on the current literature, assessment of study quality as well as a range of suggestions for further research. As in the previous chapters, I highlight the absence of youth golf literature in this area.

Throughout Part One, I identify a common theme across all three systematic reviews. The research into youth golf physical preparation is sparse and in need of growth across all topics. I, therefore, decide to develop this knowledge gap in the subsequent experimental chapters.

1.8.2 Part Two: Establishing the Impact of Warm-up on Youth Golf CHS and perceived shot quality

In this part, I take the first directed step towards youth specific research, by investigating the impacts of a warm-up on CHS and perceived shot quality:

Chapter Five: Following on from my findings in Chapter Two, and the subsequent decision to contribute to youth golf literature, I seek to explore impacts of warm-up on CHS on perceived shot quality in youth golfers. Using a counterbalanced repeated measures design, eight male and 13 female youth golfers complete a control, club only warm-up and an exercise based dynamic warm-up followed by club warm-up on three non-consecutive days. I take maximal clubhead speed and self-reported shot quality measures as dependent variables. I observe improvements in clubhead speed and self-reported shot quality in the dynamic warm-up combined with club warm-up. No significant differences are seen in the club-warm up only or control groups for either clubhead speed or self-reported shot quality. Within this chapter I demonstrate the importance of using physical warm-up before playing golf, for its positive impacts on clubhead speed and self-reported shot quality.

1.8.3 Part Three: Identifying Physical Characteristics which relate to Youth Golf CHS

In this part, I take steps to understand better which physical characteristics are related to CHS in youth golfers:

Chapter Six: Building on from Chapter Three, and with the aim of developing more high-quality youth golf literature in the area, I seek to investigate the relationships between a range of physical characteristics and clubhead speed in youth golfers. 36 male and 33 female golfers aged 13-17 take part in the study, and a correlational design is used to assess relationships between CHS and anthropometric, strength and power measurements. Findings indicate strong relationships between clubhead speed and body mass as well as upper, lower and whole-body explosive strength. This information goes on to help with the programme design and selection of dependent variables in Chapters Eight and Nine.

1.8.4 Part Four: Establishing the Impact of Resistance Training on Youth Golf CHS and BS

In this part, I explore the impacts of resistance training on youth golf CHS and BS, and first steps are taken to understand optimisation of programme design:

Chapter Seven: In a view to advance findings from Chapter Four by adding more youth literature in this area, and with insights gathered in Chapter Six, I design an interventional study to test the impact of youth resistance training on clubhead and ball speed. I use a quasi-experimental design and assigned 39 male golfers aged 11-17 years either an intervention or control group. A strength and conditioning coach then delivers a 12-week resistance training programme to the intervention group, and improvements in clubhead speed, ball speed, body mass, countermovement jump height and predicted power, as well as modified pull-ups, are tracked as dependent variables. After 12-weeks, the study demonstrates that increases in explosive strength, mass, clubhead speed and ball speed are possible through a once-weekly resistance training programme for youth golfers.

Chapter Eight: Having established the positive role resistance training can play on CHS, BS and physical performance in youth players, I seek to investigate further the optimisation of training based on the findings in Chapters Six and Seven. Within this chapter I also further the research in programme optimisation for golf, an area identified as lacking in Chapter Four. One of the key findings in Chapter Six is the strong relationship between rotational and horizontal medicine ball throws and clubhead speed. Therefore, this investigation compares explosive medicine ball exercises against static trunk training in an otherwise identical resistance training programme using a quasi-experimental crossover design. 15 male youth golfers take part in this experiment, I use clubhead speed, ball speed, as well as peak velocity for rotational and chest medicine ball, throws as dependent variables to evaluate the programme. While this study demonstrates pre/post improvements in golf CHS and BS measures, the study is unable to demonstrate improved outcomes for the medicine ball throw group.

1.8.5 Part Five: Conclusions

In this part, I bring together the findings from this thesis and discuss them as a whole body of work.

Chapter Nine: I present the conclusions of the thesis within this chapter. The research questions are addressed based on outcomes discussed in previous chapters. I discuss the novelty and potential impact of the research within this thesis. I go on to identify directions for further development of the strength and conditioning youth golf literature.

2 Chapter Two: A Systematic Review of Warm-up on Golf Performance

2.1 Chapter Outline

In this chapter, I present a systematic review of warm-up and its effects on golf performance. This review provides context to subsequent chapters and supports my identification of knowledge gaps in this area. In this chapter, I also offer a quality evaluation of the literature, which alongside the gap analysis provides support for proposed future research. I identify many gaps in the literature and highlight the absence of youth warm-up research in golf.

This Chapter is organised as follows:

Section 2.2 introduces the underpinning rationale for exploring the literature on golf warm-up.

Section 2.3 presents the methodological approach taken to explore the current literature relating to warm-up and its effects on golf performance.

Section 2.4 highlights the results of the literature search and offers the findings and study quality assessments related to this work.

Section 2.5 onward offers a discussion on the current knowledge around impacts of warm-up on golf performance. The sections also present areas for future development of the research.

2.2 Introduction

The physical preparation of golfers has received increasing attention over recent years,[1, 2] and research has demonstrated links between clubhead speed and golf ability.[3, 4] Therefore, methods to maximise distance through physical interventions are worthy of attention, as are similar means to achieve improvements in shot quality and outcome. Many studies have highlighted associations between CHS, distance related variables and golf ability with physical attributes[45-47] and shown the benefits of physical training.[2, 48] Further to refining research in these areas, methods of immediate, within tournament performance enhancement are also desirable, and appropriate warm-up routines may help in this area.

Many sports use warm-up as a means of immediate performance enhancement, with evidence supporting its effectiveness.[23] Moreover, researchers have demonstrated the injury risk reduction benefits of warm-up across other sports[49] as well as within golf,[50] adding to the case for warm-up. As such, many elite golfers complete a tailored warm-up as part of their routine, with hopes of improving distance and shot quality as well as mitigating injury risk.

Despite a clear rationale from a mix of golf and non-golf literature which demonstrates the benefits of warm-up, behaviours and attitudes around warm-up in golf seem less than desirable in non-elite players, and specific research in elite professional players is sparse. Fradkin et al.[51] attended golf clubs and observed 1040 golfers and recorded warm-up behaviours, which highlighted the poor behaviours in amateurs. Findings showed that only 54.3% of golfers performed any kind of warm up. Most of the golfers who did warm-up only performed air shots, with no golfers performing any aerobic activity and very few stretching. Only 97 of the 1040 golfers completed static stretching, with an average of one repetition per stretch chosen, and 31 players completed dynamic stretching, also with an average of only one repetition completed. Fradkin et al.[52] went on to outline the self-reported behaviours and attitudes to warm-up from the same group of golfers. They found that only 3.8% of golfers reported warming up on every occasion that they played golf, with 48.3% reporting that they never warm-up. Main reasons given for warming in those that did up were to play better (74.5%), injury prevention (27%), everyone else does (13.2%), being instructed to (4.6%), and to be able to have a better rhythm in the swing (0.7%). Eight reasons offered for not warming up, which were not needing to (38.7%), not having the time (36.4%), not being bothered (33.7%), not knowing how to (10.3%), no one else does (6.5), warm-ups not working (4.1%), forgetting (0.2%) and finally not being told to (0.1%). Similar work has also demonstrated poor warm-up practices.[50,53] With Henry et al.[53] reporting completion of a warm-up in 88.9% cases, but with 96.9% hitting range balls, 62.5% completing static stretches, 12.5% dynamic stretches and 3.1% walking. Whereas Fradkin et al.[50] reported 56.5% seldom or never warming up. With 44.4% of those who warm-up having reported any stretching, 26.1% reported air swings, and finally, only 1% of those who warmed up reported any form of aerobic exercise. They also found very few players knew how to warm-up to achieve performance benefits or reduce the risk of injury.

Overall, the results from the studies mentioned above indicate the need for a cultural change within the sport with regards to warm-up practices and the need for a better player understanding of the role of warm-up on performance. Golfers were motivated to warm-up to improve performance and reduce injury risk but lacked knowledge about the best ways to warm-up. As a result, it is essential that the literature be able to offer answers to these players, by providing information on how and why warm-ups should be carried out. Also improved dissemination of this literature to the individuals who play the sport is required. Within elite golf, players are perhaps more likely to be completing warm-ups with more regularity than those studied in the above literature, so specific and evidence-informed recommendations need to be given to ensure optimal performance and results for these players. Therefore, this literature review evaluated the current research surrounding impacts of warm-up on golf performance and secondly assessed the quality of studies relating to warm-up on golf performance. Achieving these aims may lead to clarity of information about desirable warm-up practices based on current literature, which will be of benefit to coaches, therapist and fitness staff who may be involved in players' education. The review will also allow for the identification of areas worthy of further investigation.

2.2.1 Research Questions

My purpose within this chapter was to contribute towards Research Question 1 *'What is the scope of literature exploring physical preparation of the golfer in areas of warm-up, physical characteristics associated with golf performance and the use of strength and conditioning interventions to enhance performance?'*. I would achieve this purpose by answering Research Question 1(i)*'What is the scope of literature investigating the impacts of warm-up on golf performance?'*. By addressing the following Research Objectives, I was able to achieve this purpose:

- Select and administer an appropriate systemic literature search strategy to fully capture relevant research investigating the impacts of warm-up on golf performance.
- Critically evaluate and present the results of the literature search, outlining the current research in this field and the typical findings of this literature.
- Present a quality analysis of results using the Physiotherapy Evidence Database(PEDro) scale.
- Identify gaps in the literature worthy of further exploration throughout this thesis.

2.3 METHODS

2.3.1 Identification of Studies

A systematic review was completed in-line with the Preferred Reporting Items of Systematic Reviews and Meta-Analysis (PRISMA) guidelines. A systematic search of studies which had evaluated the performance impact of warm-ups through interventional study was conducted. Four online library databases were used for the search: PubMed, CINAHL complete, SPORTDiscus, MEDLINE. Combinations of the following search terms were used to find the studies: ‘golf', ‘golfers', ‘golfer' combined with ‘warm-up', warm up', ‘warmup', ‘warming-up', ‘warming up', ‘exercise', ‘prior exercise'. A four-stage process was used to complete the review. Stage one consisted of searching the databases using the search terms outlined, for research paper titles following previous recommendations.[54] Stage two involved screening papers based on a review of the title and abstract. Stage three consisted of a full-text review of papers, completed alongside an assessment of relevance. Finally, reference lists of included papers were checked for additional articles.

2.3.2 Criteria for Inclusion

Papers were assessed for eligibility based on the following criteria: (1) investigated the effects of warm-up on a golf performance measure; (2) all participants were golfers; (3) the study design was experimental; (4) used golfers without musculoskeletal injury; (5) published in English in a peer-reviewed journal.

A total of 114 studies were evaluated based on the initial search. Of studies initially reviewed seven were deemed eligible for full-text review. After review of full-texts, and per the inclusion criteria, seven papers were deemed appropriate for inclusion. Reference lists were then screened from the seven papers as described in previous work. [55] One additional study was then added as a result of this process. Thus, the final number of papers included in the review were eight (see figure 2.0).

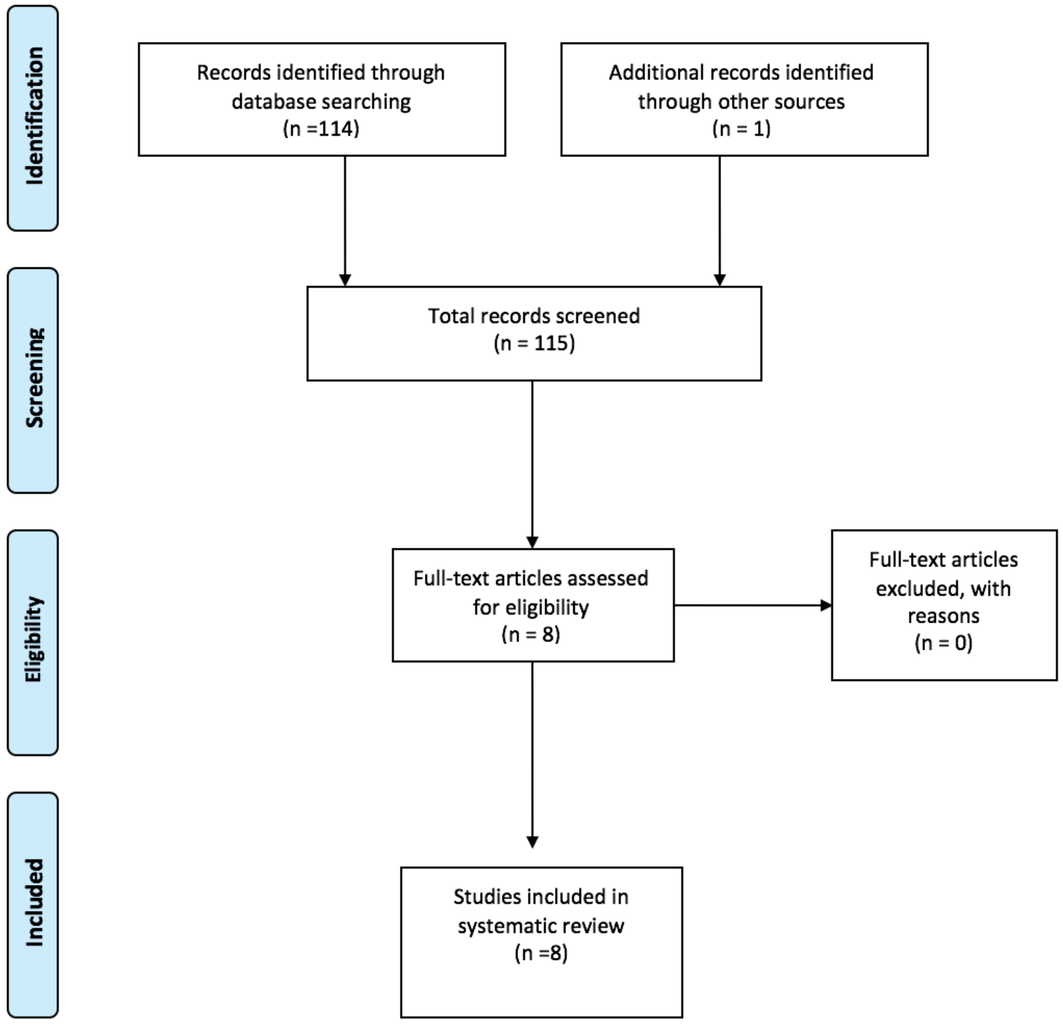

Figure 2.0. Flow diagram of search (warm-up review)

2.3.3 Study Quality

Two researchers independently assessed the included papers for quality. Quality was assessed using the Physiotherapy Evidence Database (PEDro) scale, an established and valid method.[56] Despite the validity of PEDro to appraise study quality, it should be highlighted that the scale is not well suited to addressing potential transfer to practice and therefore whether or not the research is appropriately pragmatic. However, the scale was used in absence of a more suitable option in this regard. The PEDro scale is shown in figure 2.0. A score out of 10 was assigned for each study based on the PEDro criteria, where higher scores indicated higher quality. For this review, scores of 6-10 were considered 'high quality', 4-5 'fair quality' and 0-3 'poor quality'. If the study did not explicitly state the criterion, the score was not allocated for meeting that criterion. Papers were only evaluated for study quality if they had a control and intervention arm, pre/post studies were not included in the quality analysis. As a result, study quality was assessed in only seven of the eight papers. Bunker et al.[9] was not included in the quality assessment due to its pre/post approach as opposed to using a control group.

Table 2.0: PEDro Criteria

Number	Criteria
1	Eligibility criteria were specified
2	Participants were randomly allocated to groups (in crossover study, participants were randomly allocated an order in which treatments were received)
3	Allocation was concealed
4	The groups were similar at baseline
5	There was blinding of all participants
6	There was blinding of all therapists who administered the therapy
7	There was blinding of all assessors who measured at least one key outcome
8	Measures of at least one key outcome were obtained from more than 85% of the participants initially allocated to groups
9	All participants for whom outcome measures were available received the treatment or control condition as allocated or, were this was not the case, data for at least one key outcome was analysed by 'intention to treat'
10	The results of between-group statistical comparisons are reported for at least one key outcome.

2.4 RESULTS

A summary of all warm-up intervention papers is shown in table 2.1.

2.4.1 Participants

2.4.1.1 Ability

The eight studies covered a broad range of ability levels, from professionals and low to high handicap amateurs. One study investigated impacts on professionals and category one players (HCP<5),[57] three studies had a mean ability at category one,[8,58,59] one study between category one and two (HCP 6-12) using HCP<6,[10] one at category two[9] and two with HCP over 12.[7,53]

2.4.1.2 Age

Of the eight studies, none reported a mean age of under 18 years. Three reported mean ages of 18-29,[8,58,59] one at 30-39, but using a broad range of ages of 23-64 years[7] and two over 40 years.[9,53] two studies did not report a mean age, but ranges of 16-25[10] and 18-40.[57]

Table 2.1: Summary of warm-up interventions and results

Study	Sample	Control	Intervention	Performance measures	Findings
Bunker et al.[9]	n=10 Age: 45 ± 15 HCP: 10 ± 7	No warm-up (pre/post measures only)	Whole-body vibration warm-up including static and dynamic stretching after baseline measures	Sit and reach Overhead squat Driver ball speed, spin, launch angle, carry distance, total distance, accuracy	Significant improvements ($p<0.05$) were seen in sit and reach, ball speed, carry distance and total distance
Fradkin et al.[7]	n=20 Age: 39.6 (23-64 years) HCP: 19.8 (12-27)	No warm-up	Warm-up conditioning plan including exercises to increase body temperature, static stretching and air swings completed before testing and 4-5x weekly. Delivered over 5 weeks.	5-iron CHS at week 0 (baseline), 2 and 7	Significant improvements in CHS over the 5-week intervention period compared to control. 12.8% improvements in CHS immediately after warm-up 24% improvement in CHS over the 5-week intervention
Gergley et al.[58]	n=9 Age: 20.4 ± 1.8 HCP: 3.2 ± 1.6	Active dynamic (club warm-up)	Passive static stretching	Driver clubhead speed, distance, accuracy and self-report shot quality at 0, 15, 30, 45- and 60-minutes post warm-up	Significant decreases in: CHS observed at 0, 15 and 30 but not 45 or 60 minutes ball speed and self-reported shot quality reduced at all time points Accuracy in all but 60 minutes
Gergley et al.[59]	n=15 Age: 20.6 ± 1.9 HCP: 2.5 ± 1.5	Active dynamic (club warm-up)	Passive static stretching	Driver clubhead speed, distance, accuracy and self-report shot quality	Significant decreases in all measures were observed
Henry et al.[53]	n=36 Age: 63.6 ± 7.7 HCP: 15.2 ± 6.7	Dynamic sagittal plane warm-up and golf shots	Dynamic rotation specific warm-up and golf shots	5 or 6-iron x-factor and x-factor stretch pre and post warm-up	No significant difference between warm-ups Significant increases in x-factor stretch in both warm-ups but not x-factor
Moran et al.[8]	n=18 Age: 23.2 ± 3.2 HCP: 3.2 ± 2.3	No warm-up	Static or dynamic stretching	5-iron clubhead speed, ball speed, face angle, swing path and impact point at 0, 5, 15 and 30 minutes	Dynamic stretching = significantly improvements in CHS, ball speed and swing path compared to both static and no warm-up as well as impact point compared to no-warm-up. No differences were seen in face angle No differences between static and no warm-up groups All conditions were unaffected by time
Quin et al.[10]	n=100 Age: 16-25 HCP: <6	No warm-up	Myofascial trigger point therapy and static stretching or myofascial trigger point therapy, static stretching and medicine ball exercises	Hip flexor length Driver CHS, smash factor, ball flight distance and accuracy 16 different kinematic variables during the swing	Medicine ball group showed significant improvements in backswing hip turn over control Accuracy improved in both interventions over control No other significant differences were seen
Tilley & Macfarlane[57]	n=15 Age: 18-40 HCP: <2 or Professional	Active dynamic (club warm-up)	Club warm-up plus functional TheraBand exercises or club warm-up and barbell exercises	Driver CHS, distance, smash factor, accuracy and self-reported shot quality	Functional exercise band warm-up showed significant improvements in distance, accuracy and self-reported shot quality against control and barbell exercises.

2.4.2 Golf performance measures

All studies took a full swing measure of some description, with five of the eight studies reporting data from a driver,[9, 10, 57-59] two using a 5-iron only[7, 8] and one using 5 or 6-iron.[53] No studies investigated warm-up effects on short game, putting or overall score. Six of the eight papers used CHS as a golf performance measure,[7, 8, 10, 57-59] with other distance related variables such as ball speed or distance being used in five cases.[8-10, 58, 59] Only one study took no measure of CHS or distance related variables.[53] Measured shot quality through launch monitor data were taken on three occasions,[8, 10, 57] and self-reported three times.[57-59] Three of the eight papers took a direct measure of accuracy.[9, 10, 57-59] Kinematic data from within the golf swing were taken twice[10, 53] and a flexibility or movement-based score were taken twice.[9, 10]

2.4.3 Comparing dynamic against no warm-up

Of the eight papers reviewed, four used a control group with no specific warm-up.[7-10] One of the four studies[9] used a case-series approach, completing pre/post measures as control/intervention rather than using an independent group. For this review, a no warm-up group was defined as having no specific warm-up programme, including specific club warm-up routines; however, no warm-up sometimes included unstructured practice swings or air swings. Improvements were reported in CHS,[7, 8] distance variables,[8, 9] shot quality on launch monitor,[8], accuracy[10] backswing hip turn kinematics[10] and flexibility.[9] All studies had at least one measure of improved performance, with none reporting any performance detriments from a warm-up.

2.4.4 Comparing different dynamic warm-ups

Five studies compared at least two different types of warm-up strategy,[8, 10, 57-59] of which only two were testing different types of dynamic warm-ups against one another.[53, 57] Tilley & Macfarlane[57] reported improvements in distance, accuracy and self-reported shot quality from functional dynamic exercises with an exercise band over both the active dynamic club warm-up and a light barbell warm-up. The authors found no differences in CHS or shot quality measures using smash factor through a launch monitor. When investigating swing kinematic differences, Henry et al.[53] reported no significant differences in x-factor or x-factor stretch between sagittal and rotational dynamic warm-ups, bit did find improvements in x-factor stretch with both warm-ups.

2.4.5 Comparing dynamic against static warm-ups

Four papers investigated differences between static and dynamic warm-ups for golf.[8, 10, 58, 59] In two cases, static stretching was shown to worsen performance compared to a structured dynamic club warm-up, as shown through reductions in CHS, distance, accuracy and self-reported shot quality.[58, 59] These detriments in performance occurred immediately post warm-up[58, 59] as well as over the following 60 minutes[58] with only some measured return towards baseline by this time. Moran et al.[8] demonstrated no difference between a static warm-up and no warm-up and also showed increased in CHS, ball speed and swing path using a dynamic warm-up when compared to a static one. When investigators added dynamic exercises to manual therapy and static stretching warm-up, they observed no differences between groups.[10] In this case, both groups improved in accuracy, but researchers observed no improvements in CHS, distance, ball launch conditions related to shot quality, flexibility or kinematic variables.

2.4.6 Study Quality

Of the seven papers we evaluated using the PEDro scoring system (see table 2.2), two were deemed to be of high quality,[8, 10] three of fair quality[7, 53, 57] and two of low quality,[58, 59] with an overall median quality score of five (fair). Common reasons for loss of score included blinding of participants and researchers, with all but two papers not reporting blinding.[10, 57] Two studies failed to report a group randomisation process.[58, 59] Also, three papers failed to report the number of participants who completed their study from initial group allocations or whether all participants had completed the intended interventions, and if not, whether or not an 'intention to treat analysis' had been completed.[53, 58, 59] Tilley & Macfarlane[57] also failed to score in these areas, due to a drop-out of over 85% with 'no intention to treat' analysis.

Table 2.2: PEDro study quality analysis (warm-up)

Study	1 (item not used in scoring)	2	3	4	5	6	7	8	9	10	11	Score
Fradkin et al.[7]		✓		✓				✓	✓	✓		5
Gergley[58]	✓			✓						✓	✓	3
Gergley[59]	✓			✓						✓	✓	3
Henry et al[53]	✓	✓	✓	✓						✓	✓	5
Moran et al.[8]	✓	✓		✓				✓	✓	✓	✓	6
Quin et al.[10]	✓	✓	✓	✓			✓	✓	✓	✓	✓	8
Tilley & Macfarlane[57]	✓	✓		✓			✓			✓	✓	5

1. Eligibility criteria were specified; 2. Participants were randomly allocated to groups (in crossover study, participants were randomly allocated an order in which treatments were received); 3. Allocation was concealed; 4. The groups were similar at baseline; 5. There was blinding of all participants; 6. There was blinding of all therapists who administered the therapy; 7. There was blinding of all assessors who measured at least one key outcome; 8. Measures of at least one key outcome were obtained from more than 85% of the participants initially allocated to groups; 9. All participants for whom outcome measures were available received the treatment or control condition as allocated or, were this was not the case, data for at least one key outcome was analysed by 'intention to treat'; 10. The results of between-group statistical comparisons are reported for at least one key outcome.

2.5 Discussion

The primary aim of this systematic review was to evaluate the current research surrounding the impacts of warm-up on golf performance. All studies took measures of the full golf swing, often using CHS and other distance related variables as well as measures of shot quality and on one occasion, kinematics within the swing. Interventions given included golf club, dynamic and static warm-ups. On the whole, studies indicated improvements in CHS and distance variables as well as shot quality with dynamic and golf club warm-ups. Often little difference between different dynamic warm-up interventions was found however, they were shown to be more effective than club warm-ups on one occasion. Static stretching before golf resulted in adverse changes to performance measures. The findings from this review indicate that golf club and dynamic warm-ups have a positive impact on golf performance, and static stretching can have deleterious effects.

A secondary aim of this systematic review was to assess the quality of studies relating to warm-up on golf performance. The median score of the studies included for quality assessment was 5/10, which indicated a 'fair' quality. Studies predominantly failed to report randomisation, blinding, drop-out/completion rates and use of intention to treat analysis. The quality assessments, alongside the low number of studies and their relatively broad areas of investigation indicate that there is scope for further research on many aspects within this area.

2.5.1 Participants

The two main distinguishing features of the participants within the studies were ability level and age. Reporting of these features across the studies were good, but broad ranges were present across the limited number of available studies. Only four studies investigated category one golfers or better, of which only one included any professional players, three studies investigated players between category one and two, and two studies above category two. Due to the widespread across the literature, it is difficult to draw firm conclusions around any particular ability level. Likewise, a broad spectrum of ages were covered, from 18 to 29 up to 40+ years across a limited number of papers. Where researchers gave active warm-up interventions, less skilful and older players showed higher rates of improvement. Fradkin et al.[7] reported 6.7-14.4mph increases in CHS as opposed to only 2mph in the case of Tilley & Macfarlane,[57] who had the highest ability group.

Differences in age and ability are essential to consider, because athletes who are of a higher ability level, physically fitter or younger may be working at a relatively lower level during a similar warm-up than those who are not. Which may result in requirements for higher intensity warm-ups, increased warm-up time or improved warm-up specificity. Conversely, it may be that players who are of a lower ability level, less fit or older may have more to gain through warm-up due to the large possible ranges of improvement available. Whereas players working closer to the limits of the sport may have less room for improvement and therefore may be more limited in their potential for improvement. Authors have made similar speculations around warm-up in a previous discussion,[23] and while it is not clear exactly how age and ability might impact warm-up response, it is essential to consider that the findings from one group may not be entirely generalisable to the other.

Another major point of consideration with regards to age is that there was a lack of literature on youth populations. No study investigated the impact of warm-up on youth performance. This is an essential area for investigation given the impact other researchers have shown outside of golf.[11, 13] Also, previous literature has outlined the inadequate warm-up behaviours in adult golfers,[51-53] and if warm-ups positively impact youth golf populations, this may be an essential area to focus attention to support behavioural shifts in the sport. Further, there is potential for effects to differ from the other populations outlined, as discussed above, warranting specific attention.

2.5.2 Comparing dynamic warm-up against no warm-up

Only four studies have compared the effects of no warm-up against various warm-up interventions on golf performance.[7-10] All but one of the studies[10] observed significant increases in CHS and distance as a result of a dynamic warm-up. While the four studies were similar in their use of a control group, the interventions given were quite varied. Fradkin et al.[7] set out to investigate the acute effects of the warm-up with regards to golf performance, but also the longer-term effects of a five-week programme of warming up (completed over a seven-week period with pre and post-intervention testing). Their intervention group were required to complete a warm-up conditioning programme five times weekly for a five-week period, and both control and intervention groups had their clubhead speeds monitored on a regular basis. Their warm-up contained three phases. Firstly, the golfer would complete some vigorous movements to increase body temperature and range of movement, this was followed by a golf specific stretching programme and finally a progressive set of air swings, building in the range of movement and speed. Over the course of this investigation, researchers found that the acute effects of a golf warm-up increased clubhead speed (12.8% between weeks one and two). With additional increases in clubhead speed (24% total) over a five-week golf warm-up conditioning programme. Significant improvements were also observed over the five-week conditioning programme when compared to the control (p<0.001). Moran et al.[8] investigated both dynamic and static stretching against a no warm-up control. Their dynamic warm-up involved stretching of the gastrocnemius, quadriceps, hamstrings, completion of a lunge, trunk rotations, posterior shoulder and anterior shoulder/chest and triceps dynamic stretching. During the dynamic stretching interventions, three sets of exercises were completed gradually building in intensity. Unlike Fradkin et al.[7] no specific section of the warm-up focused on raising body temperature. Using a ball launch monitor, they were able to show significantly greater clubhead speeds, ball speeds, straighter swing paths, more central impact points as a result of dynamic stretching over control, as well as static stretching interventions. During the intervention by Moran et al.[8] increases in CHS were seen of 2.7mph, 4.2mph, 3.4mph and 4.0mph at 0, 5, 15- and 30-minutes post-warm-up respectively against the control group.

By contrast, Bunker et al.[9] measured the effects of an active warm-up, using a whole-body vibration platform, on flexibility, power and golf performance measures. Participants were required to complete eight different exercises on the whole-body vibration platform (forearm stretch, half push-up, cross-over, cat and dog, toe touch, sumo squat, lunge and reach, golf stand and rotate), with each exercise lasting for 30 seconds. Testing was carried out on golf ball launch conditions, overhead squat and sit and reach pre and post the outlined warm-up intervention. Their subsequent findings indicated significant improvements in ball speed, carry distance, total distance and sit and reach scores post-warm-up. However, this work did not appear to consider the investigations previously outlined. So, the researchers did not distinguish the impact of the whole-body vibration as a component of the warm-up from the process of completing a dynamic warm-up programme alone. As a result, it is not possible to understand the relative contribution of the whole-body vibration aspect of this warm-up against merely completing a dynamic warm-up alone. To draw any meaningful conclusions from this work, further research should look to separate a dynamic warm-up control against a whole-body vibration dynamic warm-up to see if any additional performance benefits were on offer.

Moreover, the use of a pre/post-test approach as opposed to using an actual control group limits the assertions which the researchers can make from the study. The work by Bunker et al.,[9] therefore, seems to add to the support of a dynamic warm-up without explicitly highlighting the contribution of whole-body vibration. Finally, Quinn et al.[10] investigated impacts of myofascial release and static stretching with or without the addition of medicine ball throws. While this study focuses somewhat on the static stretching and passive manual therapy approaches to warm-up, the inclusion of a no warm-up group and use of medicine ball throws supports its consideration in this section. In this case, both the myofascial release and static stretching with or without medicine ball throws demonstrated significant improvements in accuracy while the specific addition of a medicine ball throw to the warm-up resulted in significant improvements in backswing hip turn.

The overall results of these four papers appear to indicate that improvements in CHS, distance variables and accuracy are possible with the use of dynamic warm-ups over no warm-up. Despite one of the papers looking into whole-body vibration warm-up, due to limitations in the study design, it is not possible to advocate the use of this method above dynamic warm-up alone.

2.5.3 Comparing different dynamic warm-ups

Building on the results of the work above, two papers have looked to compare different types of dynamic warm-up against one another to determine the best approach.[53, 57] Tilley & Macfarlane[57] looked at the impact of three interventions in high-level golfers, including dynamic and resistance-based warm-ups on ball launch conditions and CHS. Using the club based active dynamic programme in Gergley[59] as a control, they also then introduced two additional testing days. One of which would require the golfer to complete the active dynamic club-based warm-up alongside a functional resistance programme using an exercise band, the second would require the participants to complete a multi-joint strength programme alongside the active dynamic warm-up. The overall findings indicated significantly increased smash factor, driving distance and consistent ball strike in functional resistance programme. No differences were seen between groups for driving accuracy or clubhead speed. No significant differences were found between the multi-joint strength programme and active dynamic stretching alone. Increases of 2mph and 1.4mph were seen for the functional exercise band warm-up and barbell resistance warm-ups respectively. These results indicate the use of specific exercises in addition to a club-only warm-up may be superior to club warm-ups alone. However, the barbell warm-up was an unusual choice of comparison to the exercise band warm-up. Interventions more similar to those used in previous golf literature[7, 8] or literature from other sports[23] may have been more appropriate comparisons. If seeking to understand the effects of barbell work on exercise performance, prescriptions more similar to those used in post-activation potentiation[60] or priming[61, 62] literature may be more appropriate, this would often involve opting for lower volumes and higher loads than those used by Tilley & Macfarlane,[57] and as a result may yield more positive results.

By contrast to Tilley & Macfarlane,[57] Henry et al.[53] investigated effects of two warm-up interventions in older (63.6 years) and less skillful (15.2 HCP) players. The warm-ups given had either a sagittal or transverse plane focus, both with the inclusion of golf shots and using a dynamic exercise approach. Their results indicated that both warm-ups have a positive impact on x-factor stretch, which has been shown to be an indicator of CHS and distance,[63] but no difference was found between intervention types. Given the previously discussed work regarding the improvements in performance from dynamic warm-ups, it is unsurprising that performance changes were seen, and the lack of difference in findings could be down to the subtle differences in the warm-up against the relatively low ability levels and high age of the participants investigated.

The work in this area is currently lacking, with one of two papers demonstrating improvements in performance between different dynamic interventions, but with an overall lack of literature in the area and a broad spectrum of abilities and ages between the two studies.

2.5.4 Comparing dynamic against static warm-ups

Four studies investigated the impact of static stretching on golf performance, an area which has been shown to have deleterious effects on explosive activities in other sports,[64] and one which is a common practice in golf warm-up.[53] Gergley[59] investigated the acute effects of passive stretching on golf performance, as measured by ball launch conditions and clubhead speed. Within this work, they looked to compare the effects of an active dynamic club warm-up against a set of passive stretches combined with the same club warm-up. Their club warm-up was progressive, which involved working through some clubs as well as the use of a weighted club. Their passive stretch programme consisted of 12 stretches, held for 10 seconds over three repetitions. The total length of the stretching programme was around 20 minutes. Their findings showed significantly decreased clubhead speed, distance, accuracy and self-reported contact quality in the static stretching group when compared to the active club warm-up alone. Gergley[58] followed their previous work, by looking into the latent effects of their previously described static stretching and active club warm-up interventions. To understand the latent effects, they followed up with previously described measures[59] every 15 minutes post-warm-up (t0, t15, t30, t45 and t60). Their findings, similar to the previous work, showed an acute decrease in all measures of performance. Also, they found that the negative performance drop from static stretching lasted through the course of the 60-minute testing, except for clubhead speed, which showed no significant differences at t45 or t60.

Moran et al.[8] investigated similar impacts of static stretching in comparison to dynamic and no warm-up interventions. Similarly, to Gergley[58] they looked at latent effects (measurements at 0, 5, 15- and 30-minutes post-warm-up). Using a ball launch monitor, they were able to show reduced CHS at 0, 5 and 30 minutes of -1.3, -.02 and -0.7mph respectively. While researchers observed trends for reductions in CHS against control, they saw no statistically significant differences. The dynamic stretching intervention showed significant improvements in CHS, ball speed and swing path against both control and static interventions, as previously mentioned. Findings were consistent over the four-time points measured, with researchers observing no statistically significant differences between the control group and the static stretching group. As discussed in a previous section, Quinn et al.[10] investigated the use of myofascial trigger point therapy and static stretching with and without medicine ball throws. Regarding findings of impacts of static stretching, it is difficult to ascertain the specific effects of the myofascial trigger point therapy and static stretch components of the intervention. Researchers reported minimal differences between groups. However, the inclusion of the medicine ball throw resulted in increased backswing hip turn. Researchers also reported no differences between the two groups against their control.

Overall, the findings from this section indicate that the use of static stretching alone or in combination with club warm-ups would be ill-advised for golfers. There may be scope for further research investigating the use of targeted static stretches within a broader scope of dynamic and club warm-ups, given the lack of integrated warm-up investigations so far.

2.5.5 Study quality

Overall study quality was fair, with only two studies scoring as high quality,[8, 10] three as fair[7, 53, 57] and two as poor quality.[58, 59] One study was not evaluated due to the experimental design being pre/post without a control group.[9] This demonstrates a need for more studies in this area. Common reasons for lower scores were varied but generally were related to randomisation, blinding, drop-out/completion rates, amounts of participants who completed interventions and lack of use of intention to treat where appropriate. Given these observations, future research in warm-up should aim to improve quality of work by ensuring a randomisation process, ensuring adequate reporting of participants entering and then participants completing the warm-up interventions as well as completion of intention to treat where appropriate. It may be challenging to complete warm-up intervention studies with blinding, given the environments in which researchers often conduct these investigations, but investigators should consider the feasibility of blinding during the study design process.

When breaking down studies by participants discussed within this review, only four papers compared warm-up against no warm-up,[7-10] two compared different types for warm-up[53, 57] and four looked intro static against dynamic warm-up.[8, 10, 58, 59] Resulting in only one poor and two high-quality studies looking into warm-up against a no warm-up group, two fair studies looking into different types of warm-up intervention to optimise approaches and two poor and two high-quality studies investigating static stretching. To date, researchers have explored warm-up across a broad range of abilities and age ranges, however, have failed to investigate impacts on youth populations. This information not only demonstrates a call for more high-quality studies but also the expansion of high-quality work in some specific areas.

2.6 Areas for Future Development

This review has highlighted and evaluated the current research on the impacts of warm-up on golf performance, as well as assessing the quality of studies. From this review, a few research areas which have been identified would benefit from further attention. Firstly, there are generally low numbers of high-quality papers in this area, and expansion in the topic would be of great benefit. Specific work should look to improve quality through randomisation, reporting of participants starting and completing the study and completion of intention to treat analysis where needed. Feasibility of blinding should also be considered during study design, although it may not always be possible.

Specific topics worthy of future work are varied given the relative infancy of this area. However, there is an apparent lack of literature investigating warm-up in youth golf, an area which is in desperate need of expansion. Only one study included any professional golfers in their work, and as such, investigations into more elite populations would be desirable. While initial research indicates performance enhancement through warm-up, there is a scarcity of work evaluating the optimisation of warm-ups by comparing differing approaches. While static stretching seems to be deleterious to performance, it may be beneficial to investigate effects when incorporated into a complete warm-up approach.

2.7 Conclusion

The evidence I have evaluated in this review shows many positive effects of completing an appropriately designed warm-up before playing golf. A good warm-up is likely to increase CHS and distance variables and may improve shot quality through enhanced ball strike and swing kinematics. It is likely that static stretching will have deleterious impacts on CHS, distance variables and shot quality, and that these effects may last for at least one hour after warm-up. Overall study quality is fair, and researchers have conducted studies across a broad range of topics and groups, although a low overall number of publications exist in this field. As such I would recommend further research in a range of areas and offer specific suggestions throughout the review. Of note, establishing youth literature in this area is a future requirement.

3 CHAPTER THREE: SYSTEMATIC REVIEW OF PHYSICAL CHARACTERISTICS RELATED TO GOLF PERFORMANCE

3.1 CHAPTER OUTLINE

In this chapter, I present a systematic review which explores the literature on physical characteristics of golfers and how they relate to performance. In the review, I provide a comprehensive analysis which gives context and support for future chapters. I compile a detailed discussion of areas investigated and areas lacking from the current literature. While identifying a range of further topics for further investigation, I emphasise the absence of literature in youth golf.

This Chapter is organised as follows:

Section 3.2 introduces the underpinning rationale for exploring the literature on the relationship between physical characteristics and golf performance.

Section 3.3 presents the methodological approach taken to explore the current literature relating to the relationship between physical characteristics and golf performance.

Section 3.4 highlights the results of the literature search and offers the findings related to this work.

Section 3.5 onward offers a discussion on the current knowledge which exists exploring the relationship between physical characteristics and golf performance. The sections also present areas for future development of the research.

3.2 Introduction

With an ever-increasing focus on physical preparation of golfers,[1] there is great value in understanding the physical characteristics associated with higher performance in specific areas of the game. The primary aim of a golf drive is to maximise distance while maintaining adequate accuracy,[1] this also applies to long irons and woods. Previous literature has demonstrated positive links between shot distance and score/ability level,[2-4] demonstrating the potential importance of this variable. Alongside distance, there may be other advantages which increased physicality will support. Golfers are required to go through large ranges of motion, produce repeatable swings, maintain specific kinematics at high speeds, produce and absorb large forces as well as endure prolonged rounds and extensive tournament schedules over varying terrain.[32] As a result, in order to design appropriate training interventions it is important we understand how specific physical qualities may relate to desirable performance measures. A clear understanding of these qualities will help the strength and conditioning coach target their development within the golfers training regime.

It is essential that we understand which anthropometric characteristics are desirable across all sports when aiming to achieve maximal performance. Many sports have their own unique set of anthropometric characteristics which offer a specific advantage to the athlete. While many common anthropometric measures are genetically pre-determined, and may therefore only offer themselves as selection criteria, others such as body composition, may be manipulated through targeted interventions.[65] Golf is physically demanding, but also exceptionally technically and tactically challenging, and as such, the identification of desirable characteristics may not be obvious, and therefore is worthy of detailed investigation. However, it is possible to postulate that higher body mass, especially lean mass, may support a golfers ability to gain shot distance, due to its potential to support the expression of greater absolute force. Moreover, taller golfers or those with greater limb lengths may be able to achieve greater distances due to their increased levers. As such, these areas are worthy of investigation and understanding.

Golfers are required to go through large ranges of motion at high velocity, and as such are likely to benefit from a high level of explosive strength. Explosive strength is dependent upon an athletes ability to exert high levels of force within a short timeframe, and as such, both measures of explosive strength, as well as maximal strength, may have significant relationships with shot distance. Previous literature has demonstrated that increased force through the lead leg, as well as high pelvic and trunk velocities, are related to distance,[32,66] which would further support the rationale for the relevance of player strength characteristics in golf. Furthermore, previous literature in a range of throwing and batting sports have demonstrated significant relationships between strength and explosive strength characteristics and performance,[67-69] indicating potential relevance to golf. Not only is the magnitude and rate of force production in golfers of interest, but also their range of motion. The golf swing is highly dynamic, requiring the athlete to achieve large ranges of motion in a number of areas, including trunk and hip.[66] Research has demonstrated significant relationships between x-factor and x-factor stretch, measures of pelvis-torso separation at the top of the backswing, to be related to shot distance.[66, 70] To achieve high levels of x-factor, a golfer will be required to have a high degree of the trunk and hip rotation within the swing. Further to this, a golfer will be required to have a high degree of external rotation in their trail shoulder to support the achievement of a high x-factor without technical breakdown. As such, it is feasible that a golfer may require high degrees of range of motion in specific areas.

While cardiovascular demands placed on the golfer are low,[32] players are required to travel extensively, compete over long durations and across multiple consecutive days, on varying terrain and over increasingly extended seasons. As such, while a less prominent area, this is indeed one worthy of investigation. Likewise, due to the varying terrain, from undulations to bunkers and due to the dynamic nature of the golf swing, balance and proprioception may play a role in achieving optimal performance, and therefore should not be overlooked within research.

Therefore, in order to establish the importance of physical preparation in the game of golf, it is essential to investigate the relationships between physical characteristics and golf performance. This systematic review aimed to evaluate the current research on the relationships between golf performance measures and physical characteristics of golfers.

3.2.1 Research Questions

My purpose within this chapter was to contribute towards Research Question 1 *'What is the scope of literature exploring physical preparation of the golfer in areas of warm-up, physical characteristics associated with golf performance and the use of strength and conditioning interventions to enhance performance?'*. I would achieve this purpose by answering Research Question 1(ii) *'What is the scope of literature investigating the relationships between the physical characteristics of golfers and golf performance?'.* By addressing the following Research Objectives, I was able to achieve this purpose:

- Select and administer an appropriate systemic literature search strategy to fully capture relevant research investigating the relationships between physical characteristics of golfers and golf performance.

- Critically evaluate and present the results of the literature search, outlining the current research in this field and the collective findings of this literature.
- Identify gaps in the literature worthy of further exploration throughout this thesis.

3.3 METHODS

3.3.1 Identification of studies

A systematic review was completed in-line with the Preferred Reporting Items of Systematic Reviews and Meta-Analysis (PRISMA) guidelines. A systematic search of studies which had evaluated relationships between physical characteristics and golf performance was conducted. Four online library databases were used for the search: PubMed, CINAHL complete, SPORTDiscus, MEDLINE. Combinations of the following search terms were used to find the studies: 'golf', 'golfers', 'golfer' combined with 'strength', 'conditioning', 'fitness', 'physiology', 'anthropometrics', 'flexibility', 'range of motion', 'balance', 'exercise', 'resistance training', 'power', 'explosive strength', 'physical characteristics', 'relationship'. A four-stage process was used to complete the review. Stage one consisted of searching the databases using the search terms outlined, for research paper titles following previous recommendations.[54] Stage two involved screening papers based on a review of the title and abstract. Stage three consisted of a full-text review of papers, completed alongside an assessment of relevance. Finally, reference lists of included papers were checked for additional articles.

3.3.2 Criteria for inclusion

Papers were assessed for eligibility based on the following criteria: (1) included assessment of relationships among golfers; (2) included an assessment of a relationship between a physical characteristic and a measure of golf performance; (3) the study design was experimental; (4) the study was not an intervention; (5) used golfers without musculoskeletal injury; (6) published in English in a peer-reviewed journal.

A total of 529 studies were evaluated based on the initial search. Of studies initially reviewed, 23 were deemed eligible for full-text review. After review of full-texts, and per the inclusion criteria, 18 papers were deemed as appropriate for inclusion. Reference lists from the 18 papers were then screened as described in previous work.[55] Four additional studies were then added via this process. Thus, the final number of papers included in the review were 22 (see figure 3.0).

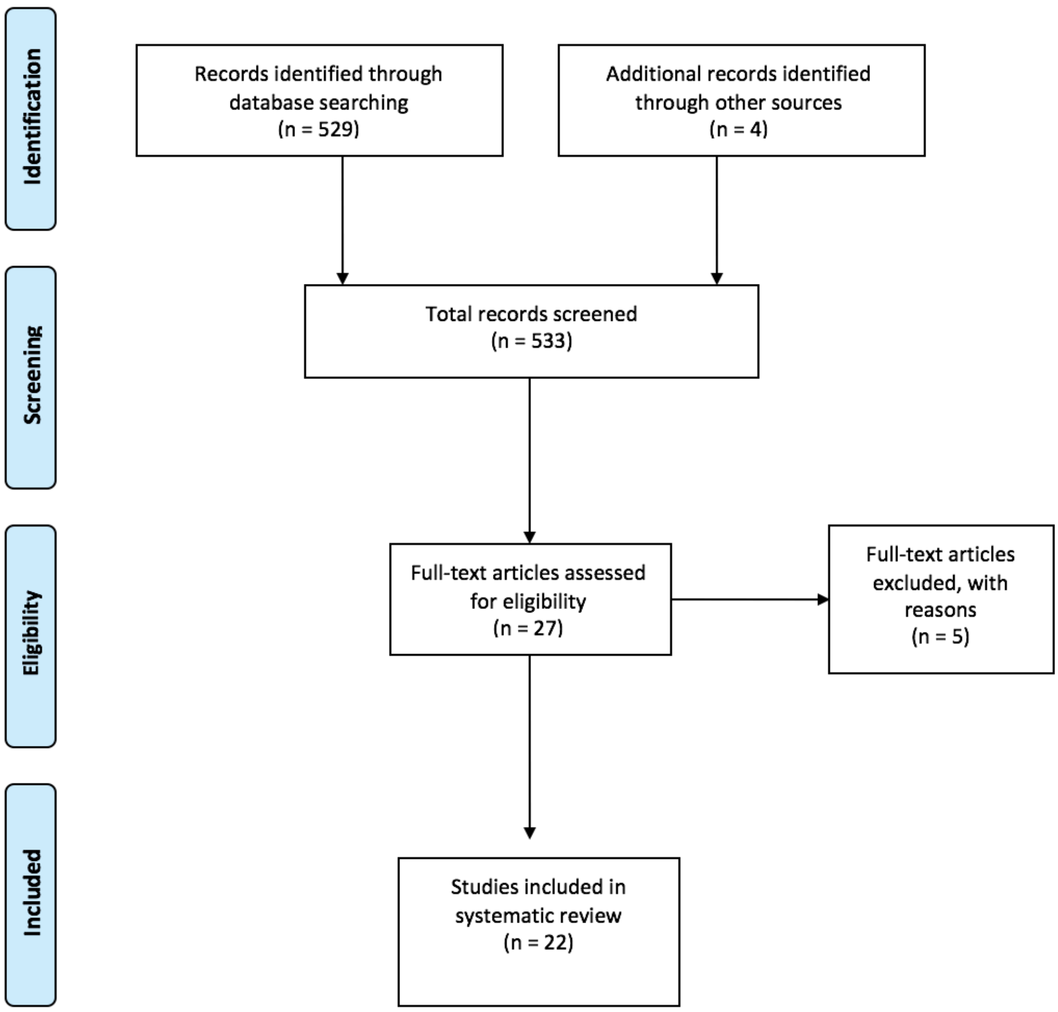

Figure 3.0. Flow diagram of search (physical characteristics review)

3.4 RESULTS

When explaining the results of research within this chapter, there are frequent reference to r values. For the purpose of this work, correlations were deemed to be weak if r<0.30, moderate if r=0.30-0.50 and strong if r>0.50 as previously reported in similar literature.[71]

3.4.1 Participants

3.4.1.1 Ability level

A wide range of ability levels were used in the included papers, from professionals and high-level amateurs to a more typical lower level golfer. Of the papers which compared pooled group physical characteristics data against golf performance measures, four used professional golfers,[72, 73] national level players[46] or NCAA division I golfers[74] with no reported handicap. A further six used category one golfers (HCP <5).[45, 70, 75-78] Category two golfers (HCP 6-12) were used on two occasions[71, 79] and HCP 12+ golfers were used on two occasions.[80, 81] Seven of the studies used a wide range of abilities, often comparing data between ability levels, and offered no pooled HCP data,[4, 47, 82-86] with one paper not offering any measure of golf ability but defining levels of regular golf participation.[87].

3.4.1.2 Age

None of the 22 studies reported a mean age of under 18 years. 13 of the studies who reported age of participants investigated golfers between 18-29 years.[45-47, 70, 71, 74, 75, 78, 80, 81, 84-86] Six of the papers investigated participants with ages between 30-39 years[72, 73, 76, 77, 79, 87] and one study used players over 40 years.[4] In one case, a broad range of ages were used, with no pooled data[83] and one study failed to report the age of its participants.[82]

3.4.2 Golf performance measures

CHS was the most commonly used measure of golf performance, with 13 of the 22 studies using it. Where researchers did not use clubhead speed, they often included driving distance or ball speed,[46, 47, 78, 79] these measurements were also regularly used in conjunction with CHS. Drivers were the dominant club of choice for evaluating CHS and distance related variables. When researchers used other clubs, they were irons and in conjunction with driver data.[46, 87] Researchers used a wide range of methods when evaluating ability level against a physical performance measure. Investigators made direct comparisons against golfer handicap,[78, 82] grouped players by handicap,[4, 81, 84] compared players by their average number of strokes[46, 47, 86] or classified them into professional, amateur and other ability groups.[47, 73, 83] Four studies looked into kinematic measures during the golf swing, using a range of methods.[70, 72, 80, 82] Researchers also evaluated putting and short game ability.[46, 47, 78, 86]

3.4.3 Anthropometrics

Of the 22 studies reviewed, ten reported relationships between anthropometric variables and golf related performance, as shown in table 3.0. On eight occasions whole body mass was investigated, making it the most frequently used anthropometric measure. When body mass was investigated, it frequently showed a positive relationship with performance variables including CHS[77, 79] and other distance[46, 78] or ability related[83, 84] measurements, with only Read et al.[71] and Leary et al.[81] finding no relationship with body mass and performance. More specific body composition measurements were also taken, including body fat percentages,[47, 81] mass in specific locations such as arm, trunk leg and chest,[47, 83, 84] waist and mid-thigh circumferences[86] as well as somatotyping of players.[83] Frequently these measurements were shown to have positive relationships with performance related variables, with the exception of Leary et al..[81] On six occasions research investigated height, with Wells et al.[46] finding strong relationships with distance-related variables, as well as improved score and short game ability. No other studies reported significant relationships. Although investigations demonstrated other specific limb length measurements relating to improved performance, these included acromiale-radiale and styloin lengths[84] as well as sitting height, leg length and arm length [46]. Although researchers did not consistently observe these findings.[71, 78, 81]

3.4.4 Explosive strength

Of the 22 studies reviewed, eight used a specific measure of explosive strength/power, as shown in table 3.1. All studies using explosive strength measurements had a golf performance measure which was distance related (CHS, ball speed, carry distance). Researchers used variations of vertical jumps on seven occasions, with a countermovement jump being the most commonly employed approach. Investigators measured jumps by height predicted power or specific force plate measurements. In studies where jump height and jump power were both taken, power displayed a stronger relationship to clubhead speed.[71, 77] Measurements of jumping ability were significantly related to distance-based performance measures in all but one case,[81]. In all other cases, researchers observed significant strong or moderate relationships. Four of the studies investigated the use of rotational medicine ball throws, and all findings reported significant relationships to clubhead speed and related variables.[71, 73, 76, 78] Seated medicine balls were also shown to have strong relationships to CHS.[71] Two papers looked into the use of an isometric mid-thigh pull test using rate of force development and peak force at set time-points and found moderate significant relationships with CHS on both occasions.[45, 81] 10 and 20m sprint[77] and maximal load at peak power in front squat and bench press[78] were also shown to be of value.

Table 3.0: Relationships between anthropometric characteristics and golf performance

Study	Sample	Anthropometric measurement	Golf performance measurement	Findings
Green et all.[79]	n=18 Age: 36 ± 13 HCP 11± 6	Lean body mass	Driving distance	Lean body mass to CHS (r=60)‡
Hellstrom (2008)[77]	n=33 Age: 34.3 ± 13.6 HCP 4.9± 2.9	Body mass	CHS	Body mass to CHS (r=0.51)‡
Kawashima et al (2003)[83]	n=128 Age: no pooled subject data HCP: not reported	Somatotype, body composition and body mass	Group: Professional Collegiate General amateur Collegiate recreational Control group (non-golfers) Senior control group (non-golfers)	Mean somatotypes of professional, collegiate, general amateur and collegiate recreational golfers were endomorphic mesomorph. Senior control group was mesomorphic endomorph. The control group was central. Bodyweight, calf skin folds, calf girths and femur width were best anthropometric measures of distinguishing between skilled and unskilled players. The sum of 4 skin folds, bicep girth and femur width were also able to distinguish between skilled and unskilled players.
Keogh et al.[84]	Low HCP Group: n=10 Age: 22.9 ± 3.4 HCP 0.3 ± 0.5 High HCP group n=10 Age: 27.8 ± 7.8 HCP 20.3 ± 2.4 (Total n=20)	Height, body mass, body mass index, sum of 4 skin folds, body fat %, fat free mass, acromiale-radiale length, radiale-stylion length, acromiale-styloin length, biacromial width, chest girth, upper arm girth	HCP group CHS Target accuracy	Moderate between group effect sizes were seen in body fat %, fat free mass, acromiale-radiale length, radiale-stylion length, acromiale-styloin length, Significant relationships were observed between: acromiale-radiale length and CHS (r=0.45)† acromiale-styloin length and CHS (r=0.45)†
Leary et al.[81]	n= 12 Age: 20.4 ± 1.0 HCP 14.5 ± 7.3	Body mass, height, body fat %	Average and maximal CHS HCP >13 HCP <13	No significant relationships were observed Height between ability levels (p=0.49, d=0.42) Body mass between ability levels (p=0.34, d=0.58) Body fat % between ability levels (p=0.55, d=0.36)
Read et al.[71]	n= 48 Age: 20.1 ± 3.2 HCP 5.8 ± 2.2	Height, body mass, arm length	CHS	No significant relationships were observed. Height to CHS (r=0.38)† Body mass to clubhead speed (r=0.34)† Arm length to CHS (r=0.30)†
Son et al.(2017)[47]	n= 90 Non-golfers: n= 33 Age: 23.45 ± 2.00 Amateurs n= 31 Age: 23.16 ± 1.91 Professionals: n= 26 Age: 21.92 ± 2.17	BMI, body fat %, % right and left arm, % trunk, % right and left leg muscle mass.	Ability level Average score Drive distance CHS Putting consistency Putting accuracy	No significant differences in BMI or body fat % between ability levels % right and left arm muscle mass significantly higher in professionals and amateurs than non-golfers. No difference between amateurs and professionals. % trunk muscle mass significantly higher in professionals and amateurs than non-golfers. No difference between amateurs and professionals. % right and left leg muscle mass significantly higher in professionals and amateurs than non-golfers. No difference between amateurs and professionals. Professional golfers % trunk muscle mass to average round score (r=-0.510)‡ Professional golfers % right arm muscle mass to putting accuracy (r=-0.516)‡ Amateur golfer % right (r=-0.381)† and left (r=-0.377)† arm muscle mass to average round score. Amateur golfer % right (r=0.488)† and left (r=0.431)† arm muscle mass to putting accuracy. No other significant relationships were observed
Son et al.[86]	n= 103 (81 males, 22 females) Age: 22.2 ± 2.0 Average round score: 83.1 ± 6.0	Waist circumference and mid-thigh circumference	Grip strength Average round score Driver distance Driver CHS Putting accuracy Putting consistency	Female waist circumference to putting accuracy (r=0.547)‡ Female mid-thigh circumference to putting consistency (r=0.490)† Male mid-thigh circumference to putting consistency (r=0.364)† No other significant findings were shown
Torres-Ronda et al.[78]	n= 44 Age: 18 ± 7.78 HCP: 1.53 ± 5.52	Height, body mass, seated height, arm span, right and left arm lengths, biacromail width	HCP Driver peak ball speed Driver average ball speed Approach shot accuracy Putting accuracy	Body mass to peak ball speed (r=0.40)† No other significant anthropometric relationships were observed
Wells et al.[46]	n= 24 Age: 22.7 ± 5.1 National golfers	Body mass, height, body mass index, sitting height, arm length and leg length	Driver ball speed Driver carry distance 5-iron ball speed 5-iron carry distance Score (strokes per round) Greens in regulation Average putt distance after a chip shot Average putt distance after a sand shot Putts (number per round)	Body mass to driver ball speed (r=0.60)‡, driver carry distance (r=0.56)‡, 5-iron ball speed (r=0.67)‡, 5-iron carry distance (r=0.67)‡, score (r=-0.48)† Height to driver ball speed (r=0.70)‡, driver carry distance (r=0.71)‡, 5-iron ball speed (r=0.69)‡, 5-iron carry distance (r=0.68)‡, score (r=-0.54)‡, putts per round (r=-0.42)† Body mass index to 5-iron ball speed (r=0.34)†, 5-iron carry distance (r=0.35)†, score (r=-0.54) Sitting height to driver ball speed (r=0.77)‡, driver carry distance (r=0.76)‡, 5-iron ball speed (r=0.73)‡, 5-iron carry distance (r=0.72)‡, score (r=-0.51)‡, average putt distance after a sand shot (r=-0.53)‡ and putts per round (r=-0.51)‡. Arm length to driver ball speed (r=0.71)‡, driver carry distance (r=0.71)‡, 5-iron ball speed (r=0.67)‡, 5-iron carry distance (r=0.66)‡, score (r=-0.55)‡, average putt distance after a sand shot (r=-0.40)† and putts per round (r=-0.39)†. Leg length to driver ball speed (r=0.34)†, driver carry distance (r=0.38)†, 5-iron ball speed (r=0.35)†, 5-iron carry distance (r=0.36)†, score (r=-0.48)†

† Moderate correlation(r=0.3-0.5) ‡ Strong correlation (r>0.5)

Table 3.1: Relationships between explosive strength/power characteristics and golf performance

Study	Sample	Physical Measures	Golf performance measures	Findings
Gordon et al.[76]	n=15 Age: 34.3 ± 13.6 HCP: 4.9 ± 2.9	Rotational medicine ball throw	CHS	Rotational medicine ball throw to CHS (r=0.54)‡
Hellstrom[77]	n=33 Age: 34.3 ± 13.6 HCP 4.9± 2.9	Squat jump, countermovement jump, and countermovement jump with arm swing (for predicted power and height) . 10 and 20m sprint time and mean power	CHS	Jumps for height and CHS (r=0.45-0.47)† Jumps using calculated power (r=0.61)‡ Sprint for time was non-significant 10 and 20m sprint mean power and CHS (r=0.49† and 0.53)‡
Lewis et al.[73]	n= 20 Age: 31.95 ± 8.7 PGA professionals	Squat jump, seated medicine ball throw, rotational medicine ball throw	CHS (groups as 'all', <30 and > 30 years of age)	All: squat jump (r=0.817)‡, seated medicine ball throw (r=706)‡, rotational medicine ball throw (r=0.57‡ but non-significant) with CHS <30: squat jump (r=0.801)‡, seated medicine ball throw (r=0.643)‡, rotational medicine ball throw (r=0.59‡ but non-significant) with CHS >30: squat jump (r=0.729)‡, seated medicine ball throw (r=0.881)‡, rotational medicine ball throw (r=0.642)‡ with CHS Squat jump and seated medicine ball throws accounted for 74% of the variance in CHS
Leary et al.[81]	n= 12 Age: 20.4 ± 1.0 HCP 14.5 ± 7.3	Isometric mid-thigh pull and vertical jump force performance characteristics	Average and maximal CHS HCP >13 HCP <13	150 milliseconds isometric mid-thigh pull with average (r=0.46)† and maximal (r=0.47)† CHS Rate of force development (0-150 milliseconds during isometric mid-thigh pull with average (r=0.38)† and maximal (r=0.36)† CHS
Read et al.[71]	n= 48 Age: 20.1 ± 3.2 HCP 5.8 ± 2.2	CMJ height, CMJ peak power, squat jump height, squat jump peak power, right and left leg CMJ height, medicine ball seated and rotational throw	CHS	CMJ height and CHS (r=0.44)† CMJ peak power and CHS (r=0.54)‡ Squat jump height and CHS (r=0.50)† Squat jump peak power and CHS (r=0.53)‡ Medicine ball seated throw and CHS (r=0.67)‡ Medicine ball rotational throw and CHS (r=0.63)‡
Torres-Ronda et al.[78]	n= 44 Age: 18 ± 7.78 HCP: 1.53 ± 5.52	Rotational medicine ball throw (1 and 2kg), countermovement jump. Front squat and bench press maximum load under optimized peak power output.	HCP Driver peak ball speed Driver average ball speed Approach shot accuracy Putting accuracy	A negative relationship was found between medicine ball throw at 1kg (r=-0.62)‡ and 2kg (r=-0.60)‡ with HCP 1RM front squat load for peak power output (r=-0.52)‡ and bench press load for peak power output (r=-0.43)† to HCP CMJ and HCP showed no significant relationship MB 1kg (r=0.54)‡ and 2kg (r=0.58)‡ to peak ball speed MB 1kg (r=0.56)‡ and 2kg (r=0.59)‡ to average ball speed CMJ to peak ball speed (r=0.47)† CMJ to average ball speed (r=0.48)† Load for peak power output in front squat (r=0.70)‡ and bench press (r=0.68)‡ to peak ball speed Load for peak power output in front squat (r=0.70)‡ and bench press (r=0.67)‡ to average ball speed 68.7% of the variance in HCP explained through 1kg medicine ball throw average velocity and height. No significant relationship was found between strength and power measures and approach shot or putting accuracy
Wells et al.[45]	n= 27 Age: 19 ± 1.45 HCP 2.7 ± 1.9	Rate of force development in isometric mid-thigh pull at 0-50, 0-100, 0-150 and 0-200 N/s, countermovement jump, squat jump and drop jump positive impulse	CHS	Significant relationships were observed between: Isometric mid-thigh pull rate of force development at 0-150 (r=0.343)† and 0-200 N/s (r=0.398)† with CHS Countermovement jump positive impulse and CHS (r=0.788)‡ Squat jump positive impulse and CHS (r=0.692)‡ Drop jump positive impulse and CHS (r=0.561)‡
Wells et al.[46]	n= 24 Age: 22.7 ± 5.1 National golfers	Countermovement vertical jump, dominant and non-dominant countermovement vertical jump.	Driver ball speed Driver carry distance 5-iron ball speed 5-iron carry distance Score (strokes per round) Greens in regulation Average putt distance after a chip shot Average putt distance after a sand shot Putts (number per round)	Significant correlations were seen between: Vertical jump and driver ball speed (r=0.59)‡, driver carry distance (r=0.60)‡, 5-iron ball speed (r=0.50)†, 5-iron carry distance (r=0.48)†, score (r=-0.59) and greens in regulation (r=0.50)† Dominant leg vertical jump and driver ball speed (r=0.73)‡, driver carry distance (r=0.75)‡, 5-iron ball speed (r=0.66)‡, 5-iron carry distance (r=0.64)‡ and score (r=-0.64)‡ Non-dominant leg vertical jump and driver ball speed (r=0.77)‡, driver carry distance (r=0.78)‡, 5-iron ball speed (r=0.70)‡, 5-iron carry distance (r=0.69)‡ and score (r=-0.69)‡

† Moderate correlation(r=0.3-0.5) ‡ Strong correlation (r>0.5)

3.4.5 Strength and strength endurance

Of the 22 studies reviewed, 13 used a specific measure of strength or strength endurance, as shown in table 3.2. Researchers used CHS or other variables related to distance as measures of golf performance in all but three cases.[4, 80, 82] Strength and strength endurance were measured in a range of ways including loaded exercises such as bench press,[78, 84] squat variations,[74, 77, 78, 84] golf-specific cable wood chop[84] and isometric mid-thigh pull.[45, 81] Others measures included grip strength,[46, 75, 77] upper body bodyweight exercises such as press-ups and pull-ups and bar-dips,[46, 77, 87] shoulder and chest,[4, 76] trunk and back[4, 46, 84, 87] and gluteal strength.[82, 80] In all cases, measures of strength were shown to have a positive relationship with CHS and other distance related measures to varying degrees. Where investigators took short game measures, they were less likely to be related to strength performance.[46, 78] Researchers generally observed stronger relationships between higher loaded or maximal strength-based exercise such as squats, bench press and grip strength than low load bodyweight and strength endurance exercises.[46, 77, 78, 84, 87]

3.4.6 Range of motion and flexibility

11 of the 22 studies investigated relationships between range of motion and flexibility with golf performance (table 3.3). A range of measures were used to assess range of motion and flexibility, including passive goniometry, sit and reach and specific exercises such as the overhead squat. On six occasions, researchers demonstrated significant relationships between range of motion and flexibility with performance, as measured through ability grouping [4, 84], golf swing kinematics.[80 70, 72] and CHS.[75] On many occasions within the same studies, significant findings were not present in a range of other variables assessed. Five studies found no significant observations concerning CHS or distance related variables.[74, 76,

[84, 85, 87] One study showed a negative relationship between flexibility and distance related variables as well as golf score.[46]

3.4.7 Balance and proprioception

Six of the studies investigated the relationships between balance and golf performance (table 3.4). Researchers measured balance in a range of ways, often using a version of a simple single leg balance test,[4, 46, 79, 80, 87] with one study using a multifaceted balance scoring system,[85] hand-eye co-ordination was also measured on one occasion.[79] Two of the six studies showed positive relationships between balance characteristics with hand-eye co-ordination[79] or driving distance.[4, 79] Two studies observed no significant relationships between balance and performance.[80, 87] Two studies demonstrated negative relationships between balance and distance,[85] greens in regulation and short game.[46]

3.4.8 Cardiorespiratory fitness

Three papers looked into the relationships between golf performance and cardiovascular fitness (table 3.5), using resting heart rate,[79] a three-minute step test[87] and a predicted VO_{2max}.[46] Wells et al.[46] reported a significant relationship between cardiovascular fitness and golf performance measures, but they failed to report the correlations associated with this measurement.

Table 3.2: Relationships between strength or strength endurance characteristics and golf performance

Study	Sample	Physical Measures	Golf performance measures	Findings
Brown et al.[75]	n=16 Age: 24.8 ± 7.3 HCP: 1.75 ± 2.35	Grip strength	CHS	Left grip strength to CHS (r=0.54)‡ Right grip strength non-significant
Callaway et al.[82]	High HCP Group (≥18): n=18 Low HCP group (<5) n=38 (Total n=56) Age: not reported	Gluteus Medius strength and gluteus maximus strength using hand held dynamometer	HCP Peak pelvis rotation speed	Gluteus Medius and maximus strength to CHS (r=0.42-0.49)† Low HCP group = significantly higher strength in gluteus Medius and maximus (P=0.000)
Gordon et al.[76]	n=15 Age: 34.3 ± 13.6 HCP: 4.9 ± 2.9	Chest strength using pec-deck	CHS	Chest strength to CHS (r=0.69)‡
Gulgin et al.[80]	n=36 Age: 25.4 ± 9.9 HCP 14.2 ± 10.4	Hip bridge on left and right sides	Swing faults: Hip extension Loss of posture Slide	Hip bridge on right side to hip extension (p=0.050) and loss of posture (p=0.028)
Hellstrom[77]	n=33 Age: 34.3 ± 13.6 HCP 4.9± 2.9	Bodyweight strength exercises, grip strength, 1-RM squat. Squat and grip strength also with relative scores	CHS	Bar dips (r=0.35)† Vertical sit-ups (r=0.42)† 4 other bodyweight exercises under r=0.30† and non-significant Right grip strength and CHS (r=0.36)† 1RM squat and CHS (r=0.54)‡ Left grip strength and relative scores non-significant
Keogh et al.[84]	Low HCP Group: n=10 Age: 22.9 ± 3.4 HCP 0.3 ± 0.5 High HCP group n=10 Age: 27.8 ± 7.8 HCP 20.3 ± 2.4 (Total n=20)	Golf specific cable woodchop, bench press, hack squat, isometric prone hold	HCP group CHS Target accuracy	Moderate between group effect sizes were seen in bench press, hack squat, isometric prone hold with a large effect size with golf specific cable woodchop. Significant relationships were observed between: golf swing specific cable woodchop and CHS (r=0.706)‡ bench press and CHS (r=0.500)† hack squat and CHS (r=0533)‡
Loock et al.[87]	n=101 Age: 38.25 ± 16.55 HCP: not reported	Sit-ups, push-ups, wall squats, lower back strength using dynamometer	Driver CHS Iron CHS Driver carry distance Iron carry distance	Significant relationships were seen between: Lower back strength and driver carry distance (r=0.470)† Push-ups (r=0.285), lower back strength (r=0.558)‡, wall squats (r=0.250) and driver CHS Lower back strength and iron carry distance (r=0.439)† Lower back strength and iron CHS (r=0.597)‡
Leary et al.[81]	n= 12 Age: 20.4 ± 1.0 HCP 14.5 ± 7.3	Isometric mid-thigh pull force characteristics	Average and maximal CHS HCP >13 HCP <13	150 milliseconds isometric mid-thigh pull with average (r=0.46)† and maximal (r=0.47)† CHS
Parchmann and McBride[74]	n= 25 Age: Males 20 ± 1.2 Females: 20.5 ± 0.8 NCAA Division I golfers	1RM back squat	CHS	1RM and CHS (r=0.805)‡
Torres-Ronda et al.[78]	n= 44 Age: 18 ± 7.78 HCP: 1.53 ± 5.52	Bench press and front squat 1RM velocity-based estimate	HCP Driver peak ball speed Driver average ball speed Approach shot accuracy Putting accuracy	1RM front squat (r=-0.48)† and bench press (r=-0.45)† to HCP 1RM front squat (r=0.64) and bench press(r=0.61)‡ to peak ball speed 1RM front squat (r=0.64) and bench press(r=0.62)‡ to average ball speed No significant relationship was found between strength and measures and approach shot or putting accuracy
Sell et al.[4]	n= 257 Age: 45.5 ± 12.8 <0 HCP group n= 45 Age: 39.2 ± 13.0 HCP -2.0 ± 2.3 1-9 HCP group: n= 120 Age: 43.7 ± 12.7 HCP 4.5 ± 2.4 10-20 HCP group: n= 92 Age: 50.9 ± 10.7 HCP 13.7 ± 2.9	Right and left hip adduction, abduction and right and left shoulder internal and external rotation strength. Torso left and right rotation strength.	HCP grouping (<0, 1-9 or 10-20)	There were significant differences in: Right hip abduction and adduction left hip abduction and right and left torso rotation strength between HCP <0 and HCP 0-9 Right hip abduction, adduction, internal and external rotation, left hip abduction, left shoulder external rotation and right and left torso rotation strength and HCP 0-9 and HCP 10-20 Right and left torso rotation strength with HCP 0-9 and HCP 10-20
Wells et al.[45]	n= 27 Age: 19 ± 1.45 HCP 2.7 ± 1.9	Isometric mid-thigh pull peak force	CHS	Significant relationships were observed between: Isometric mid-thigh pull peak force and CHS (r=0.482)†

Wells et al.[46]	n= 24 Age: 22.7 ± 5.1 National golfers	Anterior, dominant and non-dominant abdominal muscle endurance, pull-ups and push-ups in 60s, dominant and non-dominant grip strength	Driver ball speed Driver carry distance 5-iron ball speed 5-iron carry distance Score (strokes per round) Greens in regulation Average putt distance after a chip shot Average putt distance after a sand shot Putts (number per round)	Significant correlations were seen between: Anterior muscle endurance with carry distance (r=0.38)† and putt distance after a chip (r=-0.44)† Dominant abdominal muscle endurance with putt distance after a chip (r=-0.43)† Non-dominant abdominal muscle endurance with putt distance after a sand shot (r=-0.59)‡ Pull up and driver ball speed (r=0.80)‡, driver carry distance (r=0.79)‡, 5-iron ball speed (r=0.78)‡, 5-iron carry distance (r=0.76)‡, score (r=-0.64)‡, average putt distance after a chip shot (r=-0.45)†and putts per round (r=-0.41)† Push up and driver ball speed (r=0.66)‡, driver carry distance (r=0.67)‡, 5-iron ball speed (r=0.57)‡, 5-iron carry distance (r=0.55)‡, score (r=-0.49)† and putts per round (r=-0.39)† Dominant grip strength and driver ball speed (r=0.78)‡, driver carry distance (r=0.77)‡, 5-iron ball speed (r=0.78)‡, 5-iron carry distance (r=0.78)‡ and score (r=-0.68)‡ Non-dominant grip strength and driver ball speed (r=0.82)‡, driver carry distance (r=0.81)‡, 5-iron ball speed (r=0.85)‡, 5-iron carry distance (r=0.85)‡, score (r=-0.71)‡ and putts per round (r=-0.44)†

† Moderate correlation(r=0.3-0.5) ‡ Strong correlation (r>0.5)

Table 3.3: Relationships between range of motion/flexibility and golf performance

Study	Sample	Physical Measures	Golf performance measures	Findings
Brown et al.[75]	n=16 Age: 24.8 ± 7.3 HCP: 1.75 ± 2.35	Trunk ROM in sitting, trunk ROM in standing	CHS	Sitting ROM clockwise to CHS (r=0.522)‡ Sitting ROM counter-clockwise to CHS (r=0.711)‡ All standing ROM non-significant
Gordon et al.[76]	n=15 Age: 34.3 ± 13.6 HCP: 4.9 ± 2.9	Trunk Flexibility	CHS	No significant findings
Gulgin et al.[80]	n=36 Age: 25.4 ± 9.9 HCP 14.2 ± 10.4	Overhead deep squat, toe touch	Swing faults: Hip extension Loss of posture Slide	Toe touch to hip extension (p=0.015)
Joyce [70]	n=15 Age: 22.7 ± 4.3 HCP 2.5 ± 1.9	Trunk and lower trunk flexion, extension, left and right lateral bending and left and right axial rotation flexibility	Golf swing kinematics of trunk and lower trunk: Flexion/extension at top of backswing and ball impact. Lateral bending at top of backswing and ball impact. Axial rotation at top of backswing and ball impact. Maximum axial rotation Axial rotation velocity CHS	Trunk extension flexibility and lower trunk axial rotation at top of backswing (r=-0.519)‡ Trunk left lateral bending flexibility and trunk axial rotation at top of backswing (r=0.651)‡ and trunk maximum axial rotation (r=0.644)‡ Trunk right lateral bending flexibility and trunk maximum axial rotation (r=-0.583)‡ Within a generalised linear model for estimates of clubhead speed, 6 kinematic variables and 3 flexibility measures were included. Flexibility measures were: Lower trunk left axial rotation flexibility (=0.23, *t*(15)=65.64, p<0.01) Trunk right axial rotation flexibility (=0.07, *t*(15)=3.83, p<0.05) Trunk left axial rotation flexibility (=-0.10, *t*(15)=35.80, p<0.01)
Kim et al.[72]	n= 30 Age: 25-35 Professional golfers	Categorised into 'limited hip internal motion' group or 'normal hip internal motion group'	Golf kinematics: Lumbar angular displacement Right and left rotation Right and left lateral bending Flexion and extension Pelvis angular displacement Right and left rotation Posterior and anterior tilt	Limited hip internal motion group showed significantly greater lumbar angular displacement in flexion (p<0.001), right and left axial rotation (p>0.025) and right lateral bending (p=0.003) than the normal hip internal motion group. Limited hip internal motion group also showed significantly greater posterior pelvic tilt (p=0.021) than the normal hip internal motion group.
Keogh et al. [84]	Low HCP Group: n=10 Age: 22.9 ± 3.4 HCP 0.3 ± 0.5 High HCP group n=10 Age: 27.8 ± 7.8 HCP 20.3 ± 2.4 (Total n=20)	Follow through trunk rotation, backswing trunk rotation, back hand wrist adduction and abduction, internal and external hip rotation	HCP group CHS Target accuracy	Moderate between group effect sizes were seen in follow through trunk rotation, backswing trunk rotation, internal hip rotation. Back leg hip internal rotation showed a significant between-group difference. No significant relationships were observed between flexibility and CHS or target accuracy
Loock et al.[87]	n=101 Age: 38.25 ± 16.55 HCP: not reported	Lower back flexibility	Driver CHS Iron CHS Driver carry distance Iron carry distance	No significant relationships were observed
Marshall et al.[85]	n=10 (5 males, 5 females) Age: Males: 19.2 ± 1.09 Females: 19.2 ± 0.84 HCP: Males: 2 ± 0 Females: 14.8 ± 6.3	Sit and reach, total flexibility (shoulder, trunk and hip flexibility score)	CHS max CHS average Distance max Distance average	No significant relationships were observed
Parchmann and McBride (2011) [74]	n= 25 Age: Males 20 ± 1.2 Females: 20.5 ± 0.8 NCAA Division I golfers	FMS	CHS	No significant relationships were observed
Sell et al.[4]	n= 257 Age: 45.5 ± 12.8 <0 HCP group n= 45 Age: 39.2 ± 13.0 HCP -2.0 ± 2.3 1-9 HCP group: n= 120 Age: 43.7 ± 12.7 HCP 4.5 ± 2.4 10-20 HCP group:	Right and left shoulder flexion, extension, abduction, internal and external rotation range of motion. Right and left hip flexion, extension, abduction and adduction range of motion.	HCP grouping (<0, 1-9 or 10-20)	There were significant differences in: Significant differences in right shoulder extension, abduction, external rotation and left shoulder flexion and abduction range of motion with HCP 0-9 and HCP 10-20 Right shoulder extension, external rotation and left shoulder extension range of motion with HCP <0 and HCP 10-20 Right hip extension left hip flexion and left hip extension range of motion with HCP <0 and HCP 10-20

	n= 92 Age: 50.9 ± 10.7 HCP 13.7 ± 2.9			
Wells et al.[46]	n= 24 Age: 22.7 ± 5.1 National golfers	Sit and reach and dominant and non-dominant side sit and reach	Driver ball speed Driver carry distance 5-iron ball speed 5-iron carry distance Score (strokes per round) Greens in regulation Average putt distance after a chip shot Average putt distance after a sand shot Putts (number per round)	Significant correlations were seen between: Sit and reach with driver carry (r=-0.36)†, 5-iron ball speed (r=—0.41)†, 5-iron carry (r=-0.44)† and score (r=0.43)† Dominant side sit and reach with driver carry (r=-0.35)†, 5-iron carry (r=-0.34)† and score (r=0.46)† Non-dominant side sit and reach with driver ball speed (r=-0.35)†, driver carry (r=-0.41)† 5-iron ball speed (r=-0.38)†, 5-iron carry (r=-0.40)†and score (r=0.47)†

† Moderate correlation(r=0.3-0.5) ‡ Strong correlation (r>0.5)

Table 3.4: Relationships between balance/proprioception and golf performance

Study	Sample	Physical Measures	Golf performance measures	Findings
Green et al.[79]	n=18 Age: 36 ± 13 HCP 11± 6	Hand-eye co-ordination and balance using a modified stork test	Driving distance	Average balance (r=0.56)‡ Right leg balance (r=0.62)‡ Left leg balance (r=0.48)† Hand-eye co-ordination (r=-0.60)‡
Gulgin et al.[80]	n=36 Age: 25.4 ± 9.9 HCP 14.2 ± 10.4	Single leg balance on left and right side	Swing faults: Hip extension Loss of posture Slide	No significant relationships were observed
Loock et al.[87]	n=101 Age: 38.25 ± 16.55 HCP: not reported	Balance on biodex	Driver CHS Iron CHS Driver carry distance Iron carry distance	No significant relationships were observed
Marshall et al.[85]	n=10 (5 males, 5 females) Age: Males: 19.2 ± 1.09 Females: 19.2 ± 0.84 HCP: Males: 2 ± 0 Females: 14.8 ± 6.3	Balance error scoring system test	CHS max CHS average Distance max Distance average	Balance error scoring system test and average distance (r=-0.850) in the male group only
Sell et al.[4]	n= 257 Age: 45.5 ± 12.8 <0 HCP group n= 45 Age: 39.2 ± 13.0 HCP -2.0 ± 2.3 1-9 HCP group: n= 120 Age: 43.7 ± 12.7 HCP 4.5 ± 2.4 10-20 HCP group: n= 92 Age: 50.9 ± 10.7 HCP 13.7 ± 2.9	Right and left eyes open and eyes closed balance with anterior/posterior, medial/lateral and vertical ground reaction forces	HCP grouping (<0, 1-9 or 10-20)	There were significant differences in: Right leg, eyes open anterior/posterior ground reaction force with HCP <0 and HCP 0-9 Right leg, eyes open anterior/posterior and medial/lateral ground reaction forces with HCP<0 and HCP 10-20
Wells et al.[46]	n= 24 Age: 22.7 ± 5.1 National golfers	Static balance dominant and non-dominant side	Driver ball speed Driver carry distance 5-iron ball speed 5-iron carry distance Score (strokes per round) Greens in regulation Average putt distance after a chip shot Average putt distance after a sand shot Putts (number per round)	Significant correlations were seen between: Dominant leg balance and greens in regulation (r=-0.43)† and non-dominant leg balance with average putting distance after a chip shot (r=0.50)†

† Moderate correlation(r=0.3-0.5) ‡ Strong correlation (r>0.5)

Table 3.5: Relationships between cardiovascular fitness and golf performance

Study	Sample	Physical Measures	Golf performance measures	Findings
Green et al.[79]	n=18 Age: 36 ± 13 HCP 11± 6	Resting heart rate	Driving distance	No significant differences were observed
Look et al.[87]	n=101 Age: 38.25 ± 16.55 HCP: not reported	3-minute step test	Driver CHS Iron CHS Driver carry distance Iron carry distance	No significant differences were observed
Wells et al.[46]	n= 24 Age: 22.7 ± 5.1 National golfers	Predicted VO_{2max}	Driver ball speed Driver carry distance 5-iron ball speed 5-iron carry distance Score (strokes per round) Greens in regulation Average putt distance after a chip shot Average putt distance after a sand shot Putts (number per round)	Significant relationship to performance measures were indicated, but correlations were not reported

3.5 DISCUSSION

The primary aim of this systematic review was to evaluate the current research on the relationships between golf performance measures and physical characteristics of golfers. In total, 22 studies were identified which met the criteria of this review. Studies covered a broad spectrum of age and ability levels, with research conducted on young professional and high-level amateurs through to high handicap older golfers. Across the broad spectrum of players, golf performance was most commonly evaluated using CHS and distance related variables, but handicap scores and measures of overall ability, short game, putting and golfer kinematics were also used. Physical characteristics measured commonly included anthropometric, explosive strength, strength, range of motion/flexibility, balance/proprioception and cardiorespiratory fitness. Strength, closely followed by range of motion/flexibility and anthropometrics were the most common measurements. Researchers measured balance/proprioception and cardiovascular fitness least often. The general indications from the literature were that many physical characteristics were positively related to performance. Body mass and site-specific mass were often positive indicators of CHS and distance, as were explosive strength measures via jumps, medicine ball throws and similar tests. The wide-ranging strength tests often showed positive indicators of predominantly CHS and distance related measures. Range of motion and flexibility, balance and proprioception as well as cardiorespiratory fitness were often less clear-cut, with some studies demonstrating positive relationships with some measures of performance, and others unable to find any relationship to performance.

3.5.1 Participants

Overall the literature offered a wide spread of abilities, ranging from professionals and high-level amateurs through to less skilled golfers. A total of 10 papers compared pooled data of physical characteristics against golf specific performance measures from either category one or professional golfers. These studies help give insight into the specific physical characteristics worthy of attention for those working with high-level players. Many other papers using higher level players looked into comparisons of different levels using a spread of abilities, rather than pooling data and comparing attributes to performance measures.[82] [4, 47, 83-86] While this is of use, we must exercise caution when interpreting these results, these studies are useful at outlining how good golfers compare to the rest but are less useful at indicating what specific characteristics might need to be focused on when trying to support already good golfers become better. Four of the papers evaluated players who are at category two or above. Much like the papers categorising ability levels rather than pooling data, we must consider to the generalisability of this data to higher level groups. Also, while attending to physical characteristics of lower ability golfers through training may be of some use, it is likely that many of these golfers may be able to enhance their category or score more through technical and tactical input above physical intervention.

Researchers investigated a relatively broad range of ages groups within the reviewed literature, with 13 studies investigating those age 18-29, six at 30-39 and one over 40 years of age. Two studies either failed to report age[82] or used a broad range without pooled data.[83] Overall this spread of age categories are likely to be of use to those working in higher level populations where competitors are likely to fall within the defined age categories outlined above. However, researchers did not conduct any studies on high level elite older golfers, which could be of great use given the ability for golfers to have long careers and progress onto high earning senior tours within the European or PGA tours. Further to this, no literature investigated relationships between physical characteristics and golf performance in youth elite players. Further research on youth populations should be an area of further investigation given the potential relevance for the design of youth strength and conditioning programmes, an area which many national programmes are now focusing.[88]

3.5.2 Golf performance

CHS was the most common measure of golf performance, with other distance related variables such as ball speed and carry distance being used instead of or in conjunction with CHS. CHS is an appropriate measure of performance related to a number of the included physical characteristics because it is a desirable performance area, which many players would like to improve. It is also an area which is related to golf score.[3] CHS is a measure which is less likely to be related to technical ability and one which will be less variable in different environments (indoor/outdoor) with different weather, ball quality and club technology. Therefore, the measure is one which is likely to be reasonably comparable when looking at the different findings across the literature. Finally, due to the relatively stable nature of CHS compared to other possible measurements, which are more dependent on the technical and technical ability of a player, relationships drawn towards specific physical characteristics are likely to be more related to the specific characteristic in question. However, the less technical and tactical nature of CHS does come with some limitations worthy of note, mainly that it is quite a one-dimensional measure and will not account for someone's broader ability in the game. Golf is a sport requiring a great deal of technical, tactical and technological contribution,[1, 89] and as such, a one-dimensional measure such as CHS may not highlight the broader areas of contribution which physical qualities may support.

Other measures of ability included golfing score/average number of strokes, handicap, ability group, as well as scoring during the short game and putting. In contrast to CHS, these measures give a far greater indication of the ability level of the golfers in a broader sense and therefore could be of great use. However, it is important to note that they will suffer many of the limitations which the CHS measures avoid. These measurements are likely to be open to a great deal of influence from many more factors than the physical attributes alone. Therefore, the relationships which researchers have highlighted, while in some cases statistically significant, may be primarily influenced by other factors which were not measured, due to the complexity and multi-faceted nature of the golf performance measurable in question.

Finally, investigators took kinematic measures in only four of the 22 studies evaluated.[70, 72, 80, 82] Kinematic measures are of great potential interest, because they may indicate the fundamental reasons why a technical ability or distance variable are different between players. For example, if a measure of trunk range of motion within the swing is related to improved trunk flexibility, it may be because the golfer can achieve a higher x-factor stretch, which is a kinematic variable related to distance.[63]

Within swing kinetics were not taken in any of the reviewed studies. Similarly, to kinematics, these are potentially valuable measures of golf performance. Like kinematics, the relationships made may give specific insight into the potential physical relationships and how they manifest within the swing. For example, it may be countermovement jump impulse is related to an increase in CHS, the reason could be that increased ground reaction forces during the swing are higher, which is related to distance.[43] Therefore, within swing kinematics and kinetics are of great potential future interest to expand our understanding of the underpinning within swing reasons why some physical characteristics may or may not be related to golf performance.

3.5.3 Anthropometrics

With all but six of the eight studies evaluated finding a positive relationship between total body mass and golf performance, it appears that body mass is likely to be a positive predictor of performance. In many cases, these findings were in specific relation to CHS[77, 79] or other distance variables.[46, 78] In those cases where ability was the performance measure in question,[83, 84] it could be argued that the likely contributions of this mass would be in CHS and distance, since these are the most likely areas where mass might enhance performance. Outside of total body mass, other mass-related variables were taken, including body fat percentages,[47, 81] mass in specific locations such as arm, trunk leg and chest,[47, 83, 84] waist and mid-thigh circumferences[86] as well as somatotyping of players.[83] Overall the combined findings in these areas also indicated that higher levels of mass and fat-free mass were indicative of higher-level performers and performances. As a whole, the trend towards positive relationships between CHS, distance, ability and mass are unsurprising. Golfers are required to generate high forces and achieve high segmental velocities through wide ranges of movement to maximise CHS and distance in order to shoot better scores.[43] From a physical, non-technical perspective, the club is required to contact the ball at a high velocity and with a maximal achievable force at impact to generate distance. Further to this, a golfer is not required to displace their mass to any great extent, and therefore an increase in mass of force producing muscles is unlikely to be harmful to performance and may have positive impacts on the golfers' ability to generate force and express explosive strength.[90, 91] Based on the reviewed literature, heavier golfers with lower fat mass are likely to be higher performers and be able to achieve greater CHS and distance.

With regards to height and specific limb lengths, there were a range of findings across the literature, and except for standing height, there was a limited degree of standardisation across studies. In general, findings were mixed, with only one of six studies reporting a direct relationship between height and golf performance,[46] and two of five studies finding other specific relationships between height related variables and golf performance.[46, 84] These findings demonstrate a lack of agreement across the current research regarding the potential impact of height and limb lengths on golf performance but demonstrate a tendency towards no or low relationships.

On many occasions, researchers did not measure whole body fat-free mass; however, this may be an important area of consideration for future work. Fat-free mass could be important because a larger muscle volume is likely to be one of the main reasons for the positive relationship between body mass and performance,[90, 91] and would be worthy of further investigation.

3.5.4 Explosive strength and power

Golf is a game which requires an athlete to accelerate a club through a wide range of motion at high speeds, which are heavily reliant on the golfer's ability to express explosive strength.[46] Golfers will accelerate a ball over 100mph in a fraction of a second[4] using every joint and muscle in their body. Therefore, we cannot overlook the importance of explosive strength in this game. Fortunately, many studies have investigated relationships between explosive strength and performance, mainly looking into CHS and distance related variables.

With regards to lower body explosive strength, an important determinant of maximal distance is ground reaction force within the swing,[43] which has to occur within limited time frames.[4] Therefore, it is logical that the majority of literature found relationships between lower body explosive strength characteristics outside of the golf swing and CHS and distance related measures from golf drives. Lower body explosive strength was predominantly measured using a variety of jump types. These included countermovement jumps,[45, 46, 71, 77, 78, 81] squat jumps[45, 71, 73, 77]and drop jumps.[45] Lower body explosive strength was also found to be significantly related to maximal load at peak power during a front squat.[78] The research indicated clear positive relationships between the various jump types and CHS or distance related variables. These results, indicate the potential relevance of jumping ability on distance in golf, which is likely to be due to the requirement for large ground reaction forces within the swing in order to maximise distance. These results give some indication for interventions which maximise jumping ability and their potential relevance in improving lower body explosive strength characteristics, which may, in turn, translate to enhancements in CHS and distance. Given the previously discussed relationships between mass and golf performance, there is potential for conflict between targeting interventions designed to increase mass while simultaneously trying to increase jump height/jump ability. A player with more mass or who increases their mass is likely to have a reduced jump height, even if no detriment in explosive strength is present, because of the increased physical requirements to displace their higher mass. This is highlighted in the two studies which used a combination of jump height and predicted power when assessing relationships,[71, 77] where jump power scores were more predictive of CHS than jump height in both cases. This observation is also likely to be directly relevant to the sport, golfers are not required to displace their mass during the full swing significantly, and therefore absolute as opposed to relative explosive strength and strength values are likely to be more impactful on their performances. Based on these findings we should apply some caution when evaluating jump ability of golfers during interventions or when comparing data between players. A focus on predicted jump power, or measures of impulse or peak force will be of more use than jump height due to the ability for these tests to consider the golfers' mass.

Like the lower body, upper body explosive strength was generally found to have positive relationships with CHS and distance. This is a relevant finding given the upper limb contribution towards the end of the kinetic chain sequence immediately before the transfer of energy into the club and ball. There is also a demonstrated and strong predictive ability of wrist and torso peak velocities[92] on ball velocity and therefore overall distance. So maximising upper limb velocities through upper body explosive strength expression is a crucial element to achieving maximal distances. Upper limb explosive strength ability was measured less frequently than jump ability, with only three studies isolating the quality. Researchers used upper limb-specific medicine ball throws on two occasions,[71, 73] with maximal load at peak power for bench press on the other occasion.[78] In all cases, investigators used a horizontal measure of upper limb explosive strength. Despite the infrequency of measurement, researchers observed strong relationships in all cases (r=0.67-0.71). These findings indicate the potential importance of developing upper limb-specific explosive strength ability in golfers to maximise CHS and distance, mainly horizontally.

Finally, whole body explosive strength were exercises which failed to isolate a specific segment but instead evaluated a total body explosive quality. Rotational medicine ball throws were the most commonly used whole-body explosive exercise, assessed in four of the eight studies, and were also the most movement specific exercise evaluated across all studies.

Rotational medicine ball throws were significantly related to CHS and distance in all cases. With rotational medicine ball throws being well related whole-body explosive strength activities, they are likely to be of use in determining a general explosive strength deficit than from looking at CHS alone, which may be of use in aiding programme design. However, unlike the upper and lower body evaluations, due to their golf specific nature and being a whole-body test, they are less likely to give specific focus areas to golf training programmes. However, these findings may also indicate the use of rotational medicine ball throws within golf training programmes, and specific interventions studies evaluating these interventions may be of use in further research. Researchers also measured whole body explosive strength by way of sprint times[77] and isometric mid-thigh pull force characteristics.[45, 81] Both of which found positive relationships with CHS and distance variables, indicating that they may be useful for determining explosive strength characteristics in golfers and their use as measures of intervention may be valuable. Given the previous discussion around mass and a golfers lack of requirement to displace mass, isometric mid-thigh pulls may be more useful and relevant that sprint times if giving interventions which may increase a golfers mass. Also, isometric mid-thigh pulls are a non-technical test and therefore may be of great use in the profiling of golfers total body explosive strength characteristics, whereas rotational medicine ball throws, while potentially equally useful, may suffer from higher technical requirements. If looking to identify whole body explosive strength characteristics or evaluate training interventions in golfers, a rotational medicine ball throw does not require advanced equipment such as force plates but does require space, whereas isometric mid-thigh pulls may be more demanding on required equipment but less demanding of space. Therefore, use of either method may be of use, depending on the context in which any profiling is likely to occur.

3.5.5 Strength and strength endurance

With 13 studies taking a measure of strength, this quality was the most commonly measured across the different physical characteristic categories. However, despite this frequency of measurement, it was also one of the lesser standardised qualities. Strength and strength endurance was often measured and frequently both categorised as a measure of strength. A wide range of exercises were used to determine a golfers strength, from multiple repetition bodyweight exercises through to high load repetition maximum lifts. Measures of strength often related to clubhead speed and distance related variables. While some measures of strength did positively relate to short game ability[46] this was less likely than long game.

Furthermore, measurements of strength were often more strongly related to CHS and distance variables than strength endurance was. This is logical given the requirement of a golfer to deliver large forces sequentially from the ground up in single swing repetitions interspersed with prolonged periods of rest while walking between shots and playing submaximal short game shots. Typically measures could be categorised into upper, lower, trunk and whole-body strength or strength endurance.

Most frequently used lower body strength measures were different variations of squat,[74, 77, 78, 84, 87] often taken as repetition maximum lifts of predictions, and frequently showed positive relationships with performance measures. This is again logical given the requirements of the golfer to create large ground reaction forces through the swing to achieve maximal ball displacement.[43] Therefore, being able to express large amounts of single repetition lower body force through squatting is likely to be conducive to increasing within swing ground reaction forces, and subsequently, distance, indicating their potential relevance within a golfers training programme. Gluteal strength was also a taken in two of the studies,[82] [80] through use of hand-held dynamometry[82] and hip bridges.[80] In both cases, these measures were found to be related to specific measures of performance, including handicap grouping, CHS and kinematics. The findings may be due to the role of the gluteal muscles in isometrically stabilising the lower limbs through the swing.

Regarding the upper limbs, a wide range of tests were used to evaluate strength and strength endurance. Bench press and other chest strength and strength endurance tests demonstrated significant relationships with CHS.[46, 76, 78, 84, 87] Researchers often took measures of chest strength and strength endurance from horizontal pushing movements, similar to those used for the medicine ball throws during explosive strength measurement. Therefore, these results support one another's findings, demonstrating the importance of explosive strength, maximal strength as well as, to some extent, strength endurance for golf. Although strength endurance measures often showed weaker relationships. Researchers evaluated grip strength in three of the studies[46, 75, 77] and represent an easily accessible and low skill measure of strength, as well having potential relevance to the requirement for high wrist velocities within the swing.[92] Grip strength showed generally positive relationships to CHS and distance variables, as well as relationships with golf score and short game in some instances.[46] In some instances, other measures of upper body strength were taken in multiple ranges of motion isometrically, often showing positive relationships.[4] Overall these findings indicate the relevance of upper body strength on golf performance, mainly driving distance, while simultaneously demonstrating the likely increase in relevance as the exercises become closer to maximal efforts, as with lower body strength findings.

The trunk is required to support force transmission of lower body ground reaction forces produced during the golf swing through to the upper limbs for delivery into the club. Support for this statement is on offer through the apparent relationships between trunk strength and strength endurance with golf performance.[4, 46, 77, 84, 87] Researchers measured trunk strength in a range of ways, usually using isometric hold in a range of planes of motion. As opposed to the explosive strength testing previously discussed, where researchers commonly used whole-body rotational exercises. The isometric nature of much of the testing is reasonably representative of some of the strength as opposed to the explosive strength requirements of the trunk. It is likely that the trunk will play a role in stabilising the golfer through the swing, supporting force transmission from the ground up and therefore an ability to isometrically absorb and stronger force seems desirable and supportive of the findings of the reviewed work.

Whole body strength was assessed using a golf specific cable woodchop[84], as well as isometric mid-thigh, pull peak force at 150 milliseconds[81], and over a five-second pull[45] and in all cases a significant relationship was observed. The golf specific cable woodchop has the highest relationship of the three studies (r=0.71), which is likely due to the sport specific nature of the exercise. Overall measures of whole-body strength seemed to be of use. Future research in this area may benefit from trying to combine whole body explosive strength and maximal strength testing to be able to diagnose explosive or maximal strength deficits in golfers in order to provide more detailed training recommendations.

3.5.6 Range of motion and flexibility

Researchers have extensively investigated the relationships between range of motion and flexibility with golf performance. Within the golf swing, a number of joints and muscles go through full ranges of motion at high speed,[46] including at the hips, trunk and shoulders, the x-factor is often cited as an influential component of golf performance,[93, 94] and one which would potential explain the need for greater flexibility at the trunk to maximise CHS and distance. It is, therefore, highly valuable to understand which joints and muscles are required to possess high levels of range of motion and flexibility in higher level performers, in order to guide exercise and programme design, as well as to inform interventional research.

With 11 of 22 studies reviewed taking a measure of range of motion or flexibility, the topic is one which researchers have explored well. However, with only six of the 11 studies finding significant positive relationships between their respective range of motion variables and performance, and one found a negative relationship, the impacts of flexibility on performance are not clear-cut. Of the studies which assessed range of motion and flexibility, most used a measure of CHS or distance,[46, 74-76, 84, 85, 87] with two using handicap grouping.[4, 84] Investigators also used measures of short game ability, accuracy or score.[46, 84] From all studies, only 3 evaluated within swing kinematics,[70, 72, 80] which was assessed using three-dimensional motion analysis on only two of these occasions.[70, 72] Given the potential for x-factor and other kinematic variables to impacts distance, the measurement of distance and CHS is reasonable. However, there does seem to be a lack of research into the specific relationships between flexibility and kinematic performance variables, given that they are most likely to manifest in influencing swing technique. Therefore, this may be an area of suggested future investigation.

Trunk rotational range of motion was measured independently on four occasions[70, 75, 76, 84] and as part of a composite score once,[85] which is likely due to its potential influence on the x-factor and x-factor stretch.[93, 94] Of the studies investigating trunk rotation, one found a positive relationship with CHS,[75] one found no individual relationship to any kinematic variable, but it could be included as part of a generalised linear model to estimate CHS[70] and finally one study found a relationship with handicap grouping but not CHS or accuracy.[84] The final two studies found no relationships between trunk rotation range of motion and any performance variable.[76, 85] Lower back flexibility was also assessed, but showed no significant relationship.[87] This does bring into question the role of flexibility at distinguishing performance between golfers of similar ability levels, given the mixed findings and that trunk rotation range of motion is the most easily reasoned with regards to having a direct impact on the golf swing and subsequent performance. Investigators observed similar findings in the upper and lower limb measurements as well as functional movement screen scores, where they often saw weak or no relationships, despite a wide range of variables being assessed, with range of motion distinguishing ability levels in some instances.[4] Overall the literature appears to offer mixed inconclusive evidence with regards to range of motion and flexibility and its relationships to performance. Although researchers observed differences in the two studies which assessed ability level groupings, so, it may be that range of motion and flexibility can distinguish between more substantial differences in ability through broad groupings but is less consistently able to distinguish between pooled data of similar ability groups. Further research may wish to focus on identifying a small number of potentially essential flexibility characteristics and focusing on their relationships with specific and relatable kinematic parameters within the golf swing. While the research continued to explore this area further, practitioners may wish to give flexibility measures, and interventions on a case by case basis dependent on individual need.

3.5.7 Balance and proprioception

There is an argument that an efficient golfer requires a high level of balance and proprioception. The ability to maintain great consistency and postural stability through such a dynamic movement with a wide range of motion, at high speeds on multiple surface types and undulations could require a considerable degree of balance and proprioceptive ability. Sell et al.[4] argue that the combination of balance, strength and flexibility training may be vital in reducing the risk of injury as well as performance enhancement. Balance is an area which has not been researched in great depth, however, Sell et al.[4] demonstrated that a HCP <0 of golfers were able to demonstrate a significantly better single leg balance with eyes open test score for their right leg, than HCP 0-9 and 10-20. The research found no significant differences between the left leg or eyes closed trials. Wells et al.[46] also completed a single leg balance test, measuring the total time the golfers were able to balance on one leg. The results indicated that there was a significant relationship between non-dominant leg balance with average putt distance post chip shot (r=0.50). Green et al.[79] also supported these findings when they reported right a left leg balance, as well as average balance scores during a stork test, were positively related to distance, while hand-eye co-ordination was negatively related to distance.

Conversely, Wells et al.[46] found dominant leg balance and greens in regulation to be negatively related (r=0.43) and Marshall et al.[85] observed negative relationships between their balance error scoring system and distance in five male golfers (r=-0.850). Two further studies found no relationship between balance scores and performance.[80, 87] These mixed results may be in part due to the appropriateness of selected tests of balance. Golf will have specific dynamic balance requirements, however many of the studies have used a general measure of static balance which may not be appropriate. Previous literature has outlined the importance of selecting appropriate dynamic balance tests while highlighting the task-specific nature of balance.[95] If researchers wish to investigate balance further, they should carefully consider the selection of appropriate dynamic balance tests. Also, researchers should give due consideration to the performance variable, balance may have specific relationships to aspects of the swing, and balance demands will change depending on playing environment. However, general balance may be less likely to relate to general measures of CHS and distance. Researchers should consider these factors to design targeted and appropriate measures of balance and relate them to performance outcomes which require task-specific balance ability.

3.5.8 Cardiorespiratory fitness

Investigations have given limited consideration towards the area of cardiorespiratory fitness in golfers. However, this is an area which is worthy of discussion and further inquiry. Golfers are required to walk for prolonged periods of time over an 18-hole round of golf, which will undoubtedly come with a physical cost. Courses are growing in length, may be hilly or exposed, and in some instances, the performer may be carrying their clubs. Despite this, the golfer is still required to maintain focus and control throughout a round of golf, often over consecutive days. Golfers will also be required to play up to 36 holes on some days within a tournament. Furthermore, the golfer is exposed to the elements and may confront unusually hot or cold days which could increase energy demand and impact concentration. Therefore, it seems logical to suggest that a golfer with higher cardiovascular fitness is likely to be able to tolerate the ever-changing demands of the sport more effectively. A fitter golfer may well also be able to tolerate the demands of training and practice more efficiently. In this area, despite the potential relevance of cardiovascular fitness, only one[46] of three papers found any significant relationship to performance. Wells et al.[46] observed an increased predicted VO2max through Leger multi-test run performance test score in those golfers who were more proficient. However, despite reporting this observation, specific data analysis was not offered within the study. Wells et al.[46] went on to hypothesise that these improvements did not necessarily reflect the importance of cardiorespiratory fitness for the golfer, but instead demonstrate a cross-training effect from other physical work the more competitive golfer is likely to be completed as part of their fitness regime. A potential reason for the lack of relationship could be due to the methods of cardiovascular fitness measurement, which were varied and included resting heart rate,[79] three-minute step test[87] and the predicted VO2max. These tests are unlikely to be representative of the specific cardiovascular demands of golf and therefore may not be the most appropriate measures. The design of a golf relevant cardiovascular fitness test may be required to more accurately assess a golfer's cardiovascular fitness for their sport.

Further to this, the methods of performance measurement may not be the most appropriate. Two of the three papers only assessed CHS and distance variables,[79, 87] and Wells et al.[46] measured ball speed and distance variables, as well as short game and putting ability in controlled environments as well as overall score. These measures are not necessarily representative of the potential advantages of cardiovascular fitness on golf performance. Cardiovascular fitness in golf could have impacts on decision making, concentration and swing performance over multiple long rounds of golf, outdoors in varying environments. Cardiovascular fitness may also support recovery[96] alongside an ability to deal with lifestyle factors related to touring athletes such as frequent travel.[97] Therefore, future research in this area may benefit from replicating the demands of golf over more extended periods of time and assessing the ability of the golfer to maintain performance levels against their cardiovascular fitness. A more detailed understanding of the relationships between cardiovascular fitness and these more challenging areas of investigation are likely needed in order to identify potential impacts of this quality, therefore aiding in identification of appropriate dependent variables for future interventional research.

3.6 AREAS FOR FUTURE DEVELOPMENT

While there are many potential areas for future development, it is vital that further research focus' on specific areas of interest supported by underlying theories and hypotheses. Many of the papers in this review have used a wide array of physical variables, correlated with large numbers of performance measures, which have led to inevitable significant results. For example, one study of only 24 golfers[46] looked at nine performance variables, which were assessed alongside 23 different physical and subject variables to determine predictors of performance. The researchers evaluated both correlations to performance and made comparisons between males and females. While an extreme case, this was not unique, with many of the papers evaluating large numbers of variables, some of which had no apparent rationale, despite a general premise of testing physical and anthropometric qualities against golf performance. Future research should, therefore, aim to reduce the numbers of variables used in these studies and focus on testing a few critical measures with specific and targeted research questions. This will avoid the risk of false positives while also offering more targeted and useful guidelines for researchers and practitioners to apply in their work.

Further to improving the quality of variable selection, research is currently lacking both youth and elite senior players. Therefore, more investigations into these populations would be beneficial. Moreover, researchers should look to increase the literature on the female golfer, given its relative sparsity within the current work. Investigations into kinematic and kinetic variables within the swing would be helpful in improving understanding of why specific variables are related to higher performance scores such as CHS. The reviewed literature seems to show mass and various anthropometrics to be predictive of performance. However, more work into the role of total body mass against fat-free mass amongst high-level players may be of use. Many of the papers which have investigated body composition in detail have done so with comparisons between expert and relative novice performers to look at population differences as opposed to distinguishing between high-level performers.

Regarding strength and explosive strength, the reviewed literature seems to support their relationships with performance firmly, and future research may benefit most from helping to distinguish between strength and explosive strength deficits in golfers to support more tailored training interventions from profiling. The role of balance and proprioception does not seem well supported at this time, despite a moderate number of studies, and researchers should only investigate it further if they have specific hypotheses targeted towards specific performance variables. Investigations have not extensively explored the role of cardiorespiratory fitness, but the cardiovascular demands in golf are low,[32] and the literature which has investigated this measure have failed to show stable relationships to performance. Therefore, if researchers wish to explore cardiovascular fitness further, they may wish to focus on the more complex role this characteristic may have. This will be achieved by looking into its relationship with decision making, concentration and swing performance over multiple long rounds of golf, outdoors in varying environments, its role in supporting recovery or ability to deal with lifestyle factors related to touring athletes such as frequent travel.

3.7 Conclusion

The research I have discussed in this review highlights an array of positive relationships between specific physical qualities and golf performance. Most notably, higher body mass, greater limb girths, increased whole, upper and lower body strength and explosive strength are consistently shown to have strong relationships to golf performance. While these relationships do not mean the physical qualities are causative of the performances, they do indicate possible dependent variables for future interventional research. Also, performance related physical qualities identified across the discussed literature have potential to inform programme design and areas of focus for the interventions given within future research. Regarding immediate impacts to practice, this review can support practitioners in deciding upon appropriate profiling approaches with their golf athletes.

4 CHAPTER FOUR: SYSTEMATIC REVIEW OF STRENGTH AND CONDITIONING ON GOLF PERFORMANCE

4.1 CHAPTER OUTLINE

In this chapter, I present a systematic review looking into the impact of resistance training on golf performance. In this review, I offer a detailed discussion on the current literature, assessment of study quality as well as a range of suggestions for further research. As in the previous chapters, I highlight the absence of youth golf literature in this area.

This Chapter is organised as follows:

Section 4.2 introduces the underpinning rationale for exploring the literature the impact of resistance training on golf performance.

Section 4.3 presents the methodological approach taken to explore the current literature relating to the impact of resistance training on golf performance.

Section 4.4 highlights the results of the literature search and offers the findings and study quality assessments related to this work.

Sections 4.5 onward offers a discussion on the current knowledge around the impact of resistance training on golf performance. The sections also presents area for future development of the research.

4.2 INTRODUCTION

Having established the positive relationships between a range of physical characteristics and golf performance in Chapter Three, it is logical to go on to investigate the potential impacts of interventions designed to enhance these qualities. Therefore, in this systematic review, I will discuss interventional strength and conditioning research related to golfers and offer a quality assessment of this literature.

Based on the literature addressed in Chapter Three, it appears that anthropometrics and body composition, explosive strength and strength characteristics are consistently related to CHS, distance and other golf performance measures. As a result, the enhancement of these qualities through appropriate training interventions may be desirable to improve performance. While less clear-cut, there is some evidence to suggest that flexibility and range of motion may be related to golf performance, but minimal evidence in support of balance, proprioception and cardiorespiratory qualities.

While many anthropometric qualities are largely genetically pre-determined, training interventions can improve body composition through supporting increases in lean muscle mass, and facilitating reductions in body fat,[65, 98] both of which may be desirable to the golfer. A range of methods can be used to achieve increases in lean mass, however higher volumes within training are often recommended.[98] Despite this, the evidence does also support the use of high load lower volume training in support of these goals.[98] While high and low load training interventions are both likely to support increases in lean mass, golfers will also wish to attain increases in strength. These combined goals will be achieved more efficiently through higher load, lower volume training.[98] Low volume and high load resistance training has been shown to be most effective at increasing upper and lower body 1-RM strength tests, which are also linked to golf performance.[98] Explosive strength measured through jumps and throws have been consistently shown to relate to some golf performance measures. These are characteristics which can be enhanced through resistance training. Both high load strength, as well as lower load high-velocity training, have positive impacts in these areas.[99-101] As a result, golfers may which to enhance body composition as well as strength and explosive strength characteristics related to their performance through appropriately tailored resistance training programmes.

While researchers have failed to related flexibility to golf performance across the whole body of literature, there is a sound rationale for its potential impact. Increasing the thoracic, hip and shoulder ranges of motion within the swing has the potential to increase x-factor and x-factor stretch, which has demonstrated links with performance.[70] Researchers have shown the effectiveness of various stretching methods in improving range of motion and flexibility,[102, 103] so incorporating stretching into the interventional research in golf may be of interest. With the lack of evidence supporting balance and proprioception or cardiovascular fitness, these may be areas less worthy of an interventional investigation until more evidence supports their potential performance impacts. It is likely that areas such as cardiovascular fitness may play a more involved role than currently researched, and as opposed to improving CHS, distance and accuracy, this quality may have more impact on consistency through a whole competitive season or improve the golfer's ability to deal with the travel demands of their sport.[97] As such, more research into this area may be warranted to determine the best dependent variables for interventional research to follow.

Research across a range of sports has not only shown the enhancement of body composition, strength and explosive strength but also transfer to sports performance. Investigators have consistently demonstrated improvements in ball velocities in overhead athletes,[104] and therefore it is reasonable to expect similar results in golf. So, this area is worthy of investigation. Therefore, this literature review aimed to evaluate the current research surrounding the impacts of strength and conditioning interventions on golf performance and secondly to assess the quality of studies relating to this area. Achieving these aims may lead to clarity of information about the potential impact strength and conditioning may have on golf performance, as well as provide suggestions for optimal training methods for optimising golf performance.

4.2.1 Research Questions

My purpose within this chapter was to contribute towards Research Question 1 *'What is the scope of literature exploring physical preparation of the golfer in areas of warm-up, physical characteristics associated with golf performance and the use of strength and conditioning interventions to enhance performance?'*. I would achieve this purpose by answering Research Question 1(iii)*'What is the scope of literature investigating the impacts of strength and conditioning on performance?'.* I achieved this purpose by addressing the following Research Objectives, which were to:

- Select and administer an appropriate systemic literature search strategy to fully capture relevant research investigating the impacts of strength and conditioning on performance.
- Critically evaluate and present the results of the literature search, outlining the current research in this field and the collective findings of this literature.
- Present a quality analysis of results using the Physiotherapy Evidence Database(PEDro) scale.

- Identify gaps in the literature worthy of further exploration throughout this thesis.

4.3 METHODS

4.3.1 Identification of studies

A systematic review was completed in-line with the Preferred Reporting Items of Systematic Reviews and Meta-Analysis (PRISMA) guidelines. A systematic search of studies which had evaluated the performance impact of warm-ups through interventional study was conducted. Four online library databases were used for the search: PubMed, CINAHL complete, SPORTDiscus, MEDLINE. Combinations of the following search terms were used to find the studies: 'golf', 'golfers', 'golfer' combined with 'strength', 'conditioning', 'fitness', 'physiology', 'flexibility', 'range of motion', 'balance', 'exercise', 'resistance training', 'power', 'explosive strength'. A four-stage process was used to complete the review. Stage one consisted of searching the databases using the search terms outlined, for research paper titles following previous recommendations.[54] Stage two involved screening papers based on a review of the title and abstract. Stage three consisted of a full-text review of papers, completed alongside an assessment of relevance. Finally, reference lists of included papers were checked for additional articles.

4.3.2 Criteria for inclusion

Papers were assessed for eligibility based on the following criteria: (1) The study involved evaluation of some form of resistance training (machine weights, free weights, elastic tubing, bodyweight (including plyometrics); (2) The intervention lasted a minimum of six weeks; (3) at least one measure directly related to sports performance; (4) the study design was experimental; (5) the study was interventional; (6) used golfers without musculoskeletal injury; (7) published in English in a peer-reviewed journal; (8) papers were not contained within the experimental chapters of this thesis.

A total of 371 studies were evaluated based on the initial search. Of studies initially reviewed 17 were deemed eligible for full-text review. After review of full-texts, and per the inclusion criteria, 16 papers were deemed appropriate for inclusion. Reference lists from the 16 papers were then screened as described in previous work.[55] Three additional studies were then added as a result of this process. Thus, the final number of papers included in the review were 19 (see figure 4.0).

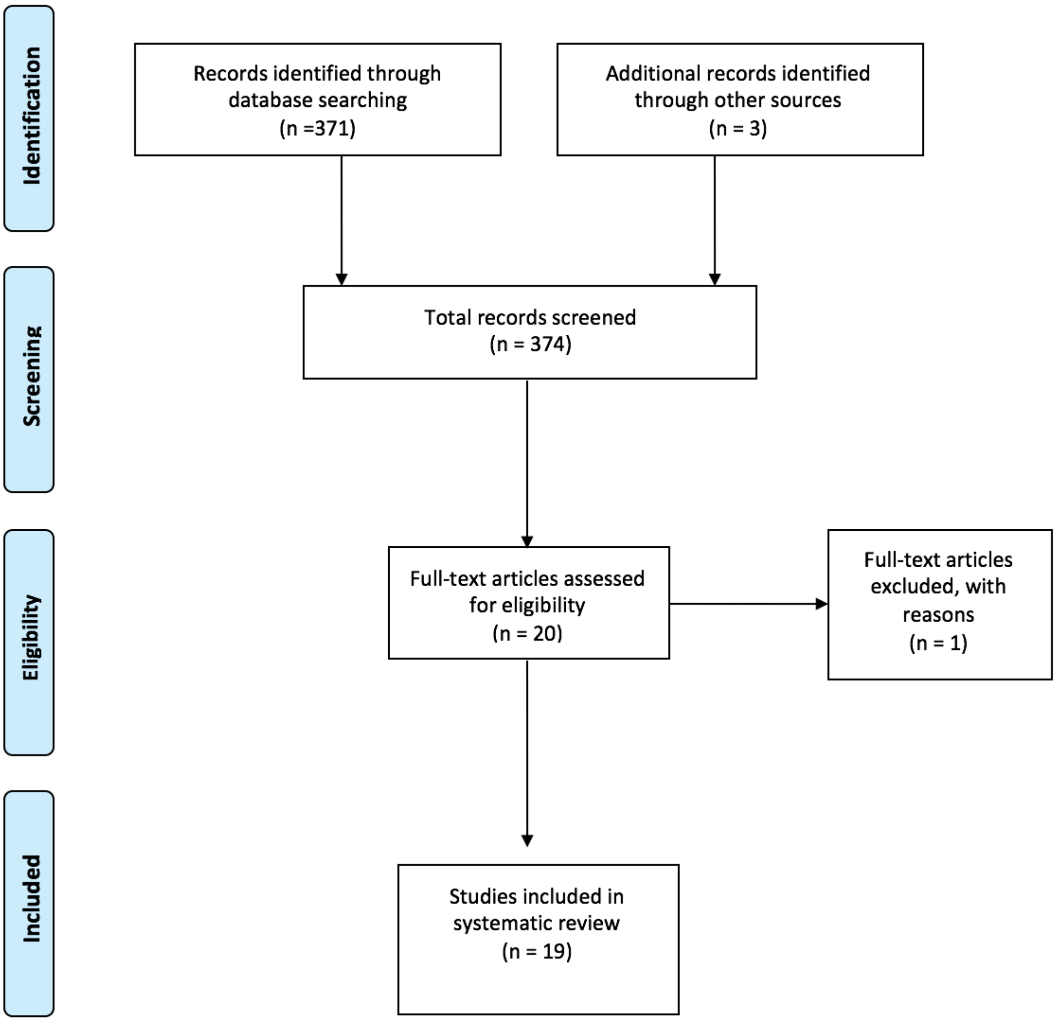

Figure 4.0. Flow diagram of search (strength and conditioning review)

4.3.3 Study quality

One researcher independently assessed the included papers for quality. Study quality was assessed using the Physiotherapy Evidence Database (PEDro) scale, an established and valid method[56]. Despite the validity of PEDro to appraise study quality, it should be highlighted that the scale is not well suited to addressing potential transfer to practice and therefore whether or not the research is appropriately pragmatic. However, the scale was used in absence of a more suitable option in this regard. The PEDro scale is shown in table 4.0. A score out of 10 was given for each study based on the PEDro criteria, where higher scores indicated higher quality. Scores of 6-10 were considered as 'high quality', 4-5 'fair quality' and 0-3 'poor quality'. Scores were not allocated for a specific criterion if the study did not explicitly state it. Papers were only evaluated for study quality if they had a control and intervention arm, pre/post studies were not included in the quality assessment. As a result, only 15 of the 19 papers were included in the quality assessment. Four papers were excluded from the quality assessment due to their pre/post approach and therefore lack of a control group.[105-108]

Table 4.0: PEDro Criteria

Number	Criteria
1	Eligibility criteria were specified
2	Participants were randomly allocated to groups (in crossover study, participants were randomly allocated an order in which treatments were received)
3	Allocation was concealed
4	The groups were similar at baseline
5	There was blinding of all participants
6	There was blinding of all therapists who administered the therapy
7	There was blinding of all assessors who measured at least one key outcome
8	Measures of at least one key outcome were obtained from more than 85% of the participants initially allocated to groups
9	All participants for whom outcome measures were available received the treatment or control condition as allocated or, were this was not the case, data for at least one key outcome was analysed by 'intention to treat'
10	The results of between-group statistical comparisons are reported for at least one key outcome.

4.4 RESULTS

4.4.1 Participants

4.4.1.1 Ability

Three categories of golfer were identified for the purpose of this review; high, moderate and low skill. High skill players were categorised as being professional, collegiate NCAA Division I or category one (HCP<5), moderate skill as category two (HCP 6-12) and low skill as HCP >12 or where researchers failed to report handicap, and other equivalent measures. For grouping, handicaps were rounded to the nearest whole number. Of the 19 papers reviewed, eight used high skill,[40, 105, 109-114] four used moderate skill[107, 108, 115, 116] and seven used low skill golfers.[106, 117-122]

4.4.1.2 Age

A wide range of ages were used within the 19 studies reviewed. Three papers conducted research on players <18.[110, 114, 120] of which only one used under 16s[120] 10 investigations were conducted on golfers ages 18-29,[40, 105, 108, 109, 111-113, 115, 116, 118] one of which did not report age, but used NCAA players, so age was likely in this category.[111] No research was completed on golfers aged 30-39 and six studies worked with over 40s[106, 107, 117, 119, 121, 122] some of which focused on or included players through their 60s and 70s.[119, 121, 122]

4.4.2 Golf performance measures

16 of the 19 papers took a measure of CHS[105-113, 115-119, 121, 122] and other distance variables such as ball speed and carry distance were taken on 10 occasions.[107-111, 113, 115, 117-119] Many of the studies taken CHS also took other measures of distance. Researchers used HCP scores on three occasions,[110, 114, 120] and were a sole performance measure in two of those instances.[114, 120] Researchers took measures of shot quality using a launch monitor on three occasions,[105, 107, 108] with putting being assessed as the only measure of short game ability once.[105] Kinematic measures were taken on four occasions,[40, 105, 107, 113] three of which used a three-dimensional analysis system. Researchers failed to use golf specific kinetic measures in any of the studies. A trackman combine test[108] and a total golf performance score[119] were also used to evaluate performance. In almost all cases, researchers observed improvement in golf performance measures after intervention from the programmes given.

4.4.3 Physical fitness measures

In all but two cases,[40, 115] physical performance measures were taken in conjunction with golf performance. Often showing improvements throughout various categories of physical performance. Anthropometric measurements were taken in six cases,[109-111, 114, 117, 119] which predominantly involved a measure of body mass and/or body composition. Explosive strength tests were used on seven of the 19 occasions,[105, 109, 110, 112, 113, 117, 118] and often included a countermovement jump or other jump score as well as medicine ball throws. Strength and strength endurance were measured on 14 occasions.[105-109, 111-114, 118-122] These were often upper and lower body 1RM tests or predictions and bodyweight exercises for repetitions. Range of motion and flexibility outcomes were taken in 11 studies,[105-108, 114, 117-122] often including trunk rotation, shoulder mobility, hip rotation and/or sit and reach. Balance and proprioception were only investigated on two occasions,[107, 119] using static balance tests. Finally, cardiorespiratory measures were taken three times.[114, 119, 121]

4.4.4 Pre/post interventions

Four of the 19 papers looked at pre/post-intervention measures without the use of a control group(table 4.1). In all but one case[108] researchers observed improvements in golf performance. The studies looked at a range of ability levels, including high,[105] moderate[107, 108] and low skilled players[106] and improvements in CHS of 3.2mph, 5.1mph and 3.1mph were seen respectively. All four studies used resistance training with external load and bodyweight exercises. Investigators also incorporated stretching as a component of most of the plans. Intervention periods ranged from seven to 11 weeks in length with sessions completed one to three times weekly. All studies showed some improvements in physical abilities as a result of training.

4.4.5 Comparing training against no training

Nine of the 19 papers compared interventions against control groups with no training or continuing normal activities (table 4.2). All but three of the studies[114, 116, 120] demonstrated improvements in at least one golf performance measure. Despite the use of a control group, on one occasion the researchers failed to statistically compare the control and intervention groups to one another, and only analysed pre/post values.[115] The studies looked at a range of ability levels, including three at high,[40, 110, 114] two at moderate[115, 116] and four at low[118, 120-122] skill levels. Where reported, improvements in CHS ranged from 2.1mph to 5mph with one study finding a reduction in CHS in both control and intervention groups.[116] Investigations also reported improvements across a range of distance variables and kinematic measures. Two of the studies specifically targeted plyometric interventions,[40, 110] one used functional training for older players[121] and all other studies used primarily resistance training with external loads and bodyweight, usually in conjunction with some stretching. Intervention periods ranged from six to 14 weeks in length, with eight weeks being the most popular length of time.[40, 110, 115, 121, 122] Sessions were completed one to three times weekly, with one study only having 1 session per week,[116] 4 using twice,[40, 110, 115, 120] two using three times per week[118, 121] and a final study requiring a minimum of 24 in an eight-week session.[122] All but two of the studies[40, 115] took physical performance measures related to their interventions and in most cases improvements in these areas were demonstrated.

Table 4.1: Pre/post studies investigating the impact of strength and conditioning interventions

Study	Sample	Intervention period	Control	Intervention	Performance Measures	Findings
Doan et al.[105]	n= 16 (6 women, 10 men) Age: 19.3 ± 1.5 HCP: Estimated 0 for men and 5-10 for women Div I athletes	11-weeks	No control	3x weekly resistance training with some stretching	Trunk rotation flexibility left and right, grip strength, bench press 1RM, estimated squat 1RM, estimated lat pull down 1RM, estimated shoulder press 1RM, medicine ball throw velocity, CHS, face angle, launch angle, putting distance at 15ft, qualitative swing video analysis	Statistically significant improvements were seen in all physical measures as well as pooled CHS and putting distance at 15ft for men.
Hetu et al.[106]	n= 17 Age: 39-63 HCP: not reported. Played golf 2-3x weekly	8-weeks	No control	2x weekly resistance training with stretching	CHS, leg extension, chest press, grip strength, sit and reach, trunk rotation	Pre/post test showed significant improvements in all measures
Lephart et al.[107]	n= 15 Age: 47.2 ± 11.4 HCP: 12.1 ± 6.4	8-weeks	No control	3-4x weekly resistance band, bodyweight and stretching	Shoulder flexion, extension and abduction, hip flexion and extension, knee extension, trunk rotation flexibility. Balance using anterior-posterior, medial-lateral, superior-inferior ground reaction force with left or right eyes open/closed Left and right torso rotation, shoulder internal and external rotation, hip adduction and abduction strength. Degrees and rotational velocities of upper torso and pelvis axial rotation and x-factor Carry distance, roll distance, total distance, ball velocity, CHS, launch angle and backspin	Significant improvements in all ranges of motion, left eye open and left eye closed anterior-posterior balance. Significant improvements in left and right torso rotation strength, left shoulder internal rotation left and right hip abduction strength. Significant reduction in pelvis axial rotation degrees and increase in upper torso rotation and x-factor velocities. Significant improvements in carry distance, total distance, ball velocity and CHS
Oliver et al.[108]	n= 43 Age: 24 ± 8.9 HCP: 8.6 ± 8.3	7-weeks	No control	1x weekly strength and endurance training – mainly bodyweight	Musculoskeletal screening tests: Left and right-side bridge, bridge and leg lift, straight leg raise, hip internal and external rotation, thoracic rotation and single leg squat. Also, front plank, thoracic extension and overhead squat Combine text, CHS, ball speed, smash factor, driving distance, carry side	Significant improvements in left side bridge with leg lift, left and right single leg squat, right thoracic rotation and thoracic extension. No golf performance improvement

Table 4.2: Studies investigating the impact of strength and conditioning interventions by comparing training against no training

Study	Sample	Intervention period	Control	Intervention	Performance Measures	Findings
Bliss et al.[110]	n=16 Age: Control: 17.4 ± 0.9 Intervention: 17.3 ± 1.5 HCP: Control: 5.2 ± 2.5 Intervention: 4.7 ± 3.0	8-weeks	No training group	Twice weekly plyometric training	HCP, body mass, 5-iron distance, shot and carry distance, clubhead speed, ball speed, countermovement jump, broad jump, kneeling chest and rotational throws	Shot distance, CHS, ball speed, countermovement jump, broad jump and keeling chest and rotational throws were all significantly improved by intervention over control. 3% improvements were seen in CHS and carry distance for the intervention group
Bull & Bridge[40]	n=16 Age: Control: 24.4 ± 8.8 Intervention: 21.5 ± 5.5 HCP: Control: 3.3 ± 1.6 Intervention: 3.8 ± 1.6 and 2 professionals	8-weeks	Continue as normal (some participants completed endurance, weight training or no training)	Twice weekly plyometric training	Pelvic position, upper torso position, head position, x-factor variables, peak segmental speeds of pelvis, torso, arm and hand, swing timings during 6-iron shots	Increases in lead arm and hand speed, x-factor and x-factor maximum rate of recoil during downswing
Fletcher & Hartwell[115]	n= 11 Age: 29 ± 7.4 HCP: 5.5 ± 3.7	8-weeks	Continued normal training (with no information given)	2x weekly resistance training with some stretching	CHS and driving distance	Pre/post significant increases in CHS and driving distance for intervention.
Kim[118]	n= 20 Training group: Age: 22.9 ± 3.7 Intervention group: Age: 21.75 ± 4.4 HCP: not reported	12-weeks	Control group used – no specific details given	3x weekly resistance and core training with stretching	Sit and reach, prone extension range of motion, repetition maximum back extension and squat, maximal isotonic lower back strength. Ball speed, CHS and carry distance	Significant between group improvements were seen in favour of the intervention for back extension range of motion, back extension and squat repetition maximum, clubhead speed and carry distance
Lamberth et al.[116]	n=10 Age: 21.4 ± 2.3 HCP: 8	6-weeks	No training group	Weekly resistance training with stretching	Intervention only 1RM bench press, 1RM leg press, countermovement jump, sit and reach. Both groups CHS.	No significant changes in CHS. Both reduced. -4.4mph reduction for intervention and -2.0mph for control. Pre/post significant improvements in bench press, leg press.
Smith et al.[120]	n= 30 Age: 12-18 Intervention HCP:15.2 ± 9.51 Control HCP: 15.26 ± 8.86	12-weeks	No training group	2x weekly resistance and bodyweight training with stretching	HCP, single leg squat level, side bridge, modified push-ups, sit and reach, shoulder mobility.	No significant differences between groups despite trends towards improved handicap
Thompson et al.[121]	n= 18 Age: 70.7 ± 7.1 HCP: not reported. Playing over 40 rounds per year	8-weeks	Continue current level of physical activity	3x weekly functional training	Between group CHS. Pre/post-test senior fitness test, including; 30 second chair stand, upper body arm curl strength, 2-minute step test, back scratch test, sit and reach, timed get up and go.	Significant increases were seen in CHS. Pre/post-test senior fitness test scores showed significant improvements in 30 second chair stand, 2-minute step test, sit and reach, timed get up and go
Thompson & Osness[122]	n=31 Age: 65.1 ± 6.2 HCP: Not reported	8-weeks	Continue current level of physical activity	Minimum of 24 resistance training sessions with stretching	10RM chest press, abdominal curl, shoulder press, seated row, lat pull-down, bicep curl, back extensions, leg curl, leg press and leg extension. Range of motion in shoulder flexion, abduction, internal and external rotation, trunk flexion, trunk rotation, hip flexion and hip internal and external rotation Mean CHS	Significant between group improvements were seen in CHS, all strength and range of motion scores except shoulder flexion, internal and external hip rotation.
Van der Ryst et al.[114]	n= 38 Age: 16-19 HCP: 5.1 ± 4.5	14-weeks	Maintain normal activities and golf	3x weekly resistance training with stretching	Bodyfat %, sit and reach, push-ups, sit-ups, grip strength, VO_{2max}, HCP. Isokinetic performance in knee extension, flexion, shoulder internal and external rotation looking at peak torque and %mass peak torque	No significant differences between groups. Pre/post-testing showed significant intervention improvements in bodyfat %, push-ups, right grip strength, left and right knee flexion peak torque, left and right knee extension % mass peak torque left and right shoulder internal and external rotation torque and % mass peak torque, VO_{2max} and HCP

4.4.6 Comparing different training interventions

Six of the 19 papers compared two different kinds of intervention (table 4.3). Despite the use of a control group, on two occasions researchers failed to statistically compare the control and intervention groups and only reported pre/post values.[111, 119] The studies looked at a range of ability levels, with four using high[109, 111-113] and two using low[117, 119] skilled players. A wide range of differences in CHS were observed, with one of the interventions leading to increases in CHS of 10mph over the control in high skill golfers[109] and small reductions in CHS in other cases.[111, 113, 117] Researchers reported significant or practically meaningful improvements in the intervention over the control on at least one golf performance measure in four cases.[109, 112, 113, 117] Researchers used a range of control, and intervention types, control groups were typically a form of 'traditional training', however this definition varied depending on context of the study. In many cases, this was a traditional core or resistance training programme,[109, 111, 113, 117, 119] but in one case was defined as a more traditional golf programme.[112] Comparators to the control group included golf specific,[109, 117] heavy resistance[112] and specialised equipment[111, 113, 119] training approaches. Intervention periods ranged from eight to 18 weeks and involved completing sessions three times weekly in all cases. All of the studies took physical performance measures related to their interventions, and in all cases, investigators reported some improvements in these areas.

4.4.7 Study quality

Of the 15 papers evaluated using the PEDro scoring system (table 4.4), two were deemed to be of high quality,[109, 112] 12 of fair quality[40, 110, 113-122] and one of low quality[111] with an overall median quality score of 5/10 (fair). Common reasons for loss of score included lack of blinding of participants and researchers, with no papers reporting a blinding process. Five studies failed to report a group randomisation process,[110, 113, 114, 118, 120] and only one paper reported concealment of allocation.[117] Six papers[40, 111, 116, 117, 121, 122] failed to report completion rates of participants or achieve 85% or greater completion, with all of these studies failing to complete an intention to treat analysis. The one paper which did achieve over 85% or greater, but below 100% failed to report intention to treat analysis.[118] Three papers failed to compare between groups statistically.[111, 115, 119] One paper also failed to show both point to point data and variability data of the groups.[114]

Table 4.3: Studies comparing the impact of different strength and conditioning interventions

Study	Sample	Intervention period	Control	Intervention	Performance Measures	Findings
Álvarez et al.[109]	n=10 Age: Control: 23.9 ± 6.7 Intervention: 24.2 ± 5.4 HCP: Control: 1.6 ± 1.1 Intervention: 2.1 ± 2.3	18 weeks & 5 weeks detraining	A weekly golf practice schedule plus 1x weekly stretching, core work and general strength exercises	Control plus 2-3x weekly maximal strength, explosive strength and golf-specific strength training	Taken on week 1, 6, 12, 18 and after 5 weeks of detraining Body mass, % body fat, % muscle mass, grip strength (left and right), squat jump, countermovement jump, driver ball speed, clubhead speed, 1RM bench press, back squat, seated row, triceps cable push-down, seated calf extension, military press	Intervention group showed significant improvements in all variables over the time points except grip strength and body mass
Cummings et al.[111]	n=10 Age: Not reported HCP: Not reported NCAA Div I	8-weeks	Normal golf training and 3x weekly resistance training programme	Normal golf training and 3x weekly resistance training programme using a Fat Grip on all bars	Body mass, average ball speed, drive distance, carry distance and CHS. 1RM pull-up, trap bar deadlift, hand grip strength.	Significant improvements were seen in the fat grip intervention for ball speed, carry distance and drive distance, as well as left hand grip strength. Significant improvements were seen in pull-ups for control group.
Hegedus et al.[117]	n= 45 Age: 58.1 ± 2.1 (of 29 completers) HCP: 20 ± 11.3 (of 29 completers)	10 weeks	3x weekly traditional resistance training	3x weekly golf specific resistance training	Mass, bone density, body composition. 7-iron and driver CHS, ball speed. Standing broad jump, seated medicine ball throw, rotational medicine ball throw, seated rotational range of motion,	Significant pooled improvements pre/post were seen in driver and 7-iron CHS and distance. Significant improvements between groups were seen in 7-iron distance for golf specific resistance training only. All pooled physical measures significant improved with no between group differences. Pooled improvements in body mass and composition, but no between group differences
Loock et al.[119]	n= 101 Age: 17-71 HCP: Not reported (25x or more yearly golf)	12-weeks	3x weekly bodyweight core home training	3x weekly COREPOWER machine	Bodyfat %, BMI, lower back flexibility, sit and reach, sit-ups, push-ups, wall squats, lower back strength, 3 minutes step test, balance, CHS, carry distance, total fitness score, total golf performance score	Significant pre/post improvements seen in all but BMI, balance, 3-minute step test for intervention and all but 3-minute step test for control.
Oranchuk et al.[112]	n= 12 Age: 20.3 ± 1.5 HCP: Not reported. NCAA Div I	8-weeks	3x weekly low load unilateral and rotational focused training	3x weekly high load and explosive resistance training	Countermovement jump. 1RM squat, deadlift and power clean. CHS,	Pre/post changes showed a significant reduction in average CHS for the control group, and a significant improvement in average CHS, 1RM back squat, deadlift, power clean and countermovement jump Significant improvement in intervention over control in average CHS, 1RM back squat, power clean and countermovement jump.
Parker et al.[113]	n= 20 Age: 22 ± 4.0 HCP: -3.0	9-weeks	3x weekly isotonic resistance training	3x weekly isokinetic resistance training	Countermovement jump loaded squat jump peak power at set loads, isotonic sitting abdominal rotations. CHS, carry distance ball speed Swing kinematics; x-factor, x-factor stretch and stretch rate, shoulder stretch and stretch rate, lead arm speed, lead arm acceleration, thorax speed, thorax acceleration, pelvis speed, pelvis acceleration.	Possible or likely beneficial effects were seen in favour of isokinetic training on carry distance, ball speed, all kinematic measures except x-factor. Also, on seated rotation force and power to dominant side. Possible or likely beneficial effects were seen in favour of isotonic training for non-dominant seated rotation force and countermovement jump. No meaningful differences were seen in CHS

Table 4.4: PEDro study quality analysis (strength and conditioning interventions)

Study	1 (item not used in scoring)	2	3	4	5	6	7	8	9	10	11	Score
Álvarez et al.[109]	✓	✓		✓				✓	✓	✓	✓	6
Bliss et al.[110]	✓			✓				✓	✓	✓	✓	5
Bull & Bridge[40]	✓	✓		✓						✓	✓	4
Cummings et al.[111]	✓	✓		✓							✓	3
Fletcher & Hartwell[115]	✓	✓		✓				✓	✓		✓	5
Hegedus et al.[117]	✓	✓	✓	✓						✓	✓	5
Kim[118]	✓			✓				✓		✓	✓	4
Lamberth et al.[116]	✓	✓		✓						✓	✓	4
Loock et al.[119]	✓	✓		✓				✓	✓		✓	5
Oranchuk et al.[112]	✓	✓		✓				✓	✓	✓	✓	6
Parker et al.[113]	✓			✓				✓	✓	✓	✓	5
Smith et al.[120]	✓			✓				✓	✓	✓	✓	5
Thompson et al.[121]	✓	✓		✓						✓	✓	4
Thompson & Osness[122]	✓	✓		✓						✓	✓	4
Van der Ryst et al.[114]	✓			✓				✓	✓	✓		4

1. Eligibility criteria were specified; 2. Participants were randomly allocated to groups (in crossover study, participants were randomly allocated an order in which treatments were received); 3. Allocation was concealed; 4. The groups were similar at baseline; 5. There was blinding of all participants; 6. There was blinding of all therapists who administered the therapy; 7. There was blinding of all assessors who measured at least one key outcome; 8. Measures of at least one key outcome were obtained from more than 85% of the participants initially allocated to groups; 9. All participants for whom outcome measures were available received the treatment or control condition as allocated or, were this was not the case, data for at least one key outcome was analysed by 'intention to treat'; 10. The results of between-group statistical comparisons are reported for at least one key outcome.

4.5 Discussion

The primary aim of this systematic review was to evaluate the current research surrounding the impacts of strength and conditioning interventions on golf performance. Many of the studies took measures of CHS and distance related variables, with some looking into shot quality, kinematics and other skill factors. Interventions given included golf-specific or general resistance training, plyometrics, exercise band and bodyweight exercises and often incorporated some stretching. Researchers compared different interventions to one another, with control groups including traditional general training or traditional golf specific or low load training. In these cases, intervention groups included golf-specific training, use of heavy resistance training and use of specialised equipment such as fat grips or COREPOWER. In cases where investigators completed pre/post studies or compared training interventions against no-training control groups golfers generally benefitted from increases in CHS and distance variables. Also, researchers reported some other benefits in kinematics and short game ability. However, these were rarely measured. Studies did not observe improvements or detriments in shot quality measured through launch monitors from the three studies measuring this variable.[105, 107, 108] In cases where papers compared different interventions to one another, findings were mixed and dependent on the training comparisons, which generally lacked standardisation across the studies. However, heavy strength and explosive strength interventions seemed favourable when they were investigated against less intense training options.[109, 112]

A secondary aim of this systematic review was to assess the quality of studies relating to the impact strength and conditioning interventions on golf performance. The median score of the studies included for quality assessment was 5/10, which indicated a 'fair' quality. Studies predominantly failed to report randomisation, concealment of group allocation, blinding, drop-out/completion rates, amounts of participants who completed interventions and lack of use of intention to treat where appropriate.

4.5.1 Participants

The reviewed literature covered a broad range of ability levels. While more papers sought to investigate high and low skill players, the research managed to encompass the effects of training interventions on all ability level categories. The ability level which a paper focus' on is worthy of significant attention when considering this literature. It is likely that higher skilled players may have different responses to lower skilled players due to their possible potential for change. Based on previous work into the relationships between physical characteristics and golf performance, it is also likely that higher level golfers may have more developed physical attributes[4, 82-84] which may also have an impact on training responses. Finally, from an applied perspective, players of higher ability levels may benefit more from physical training because they have already maximised the impact of technical and tactical proficiency in some areas, so smaller improvements become more worthwhile. Whereas much larger effects may be required to warrant lower skill players pursuing training interventions for performance enhancement, because they may have so much still to gain from investing more time in refining technical and tactical components of the game. Also, worth noting is the training history of the golf populations used in the studies, and therefore for likely responses to training. Many of the studies used relatively untrained individuals, with some using more trained players. Further to this, as previously mentioned, some more skilled players are likely to have improved physical characteristics associated with their higher performance levels. As such, it is worth noting that those players with less experience are more likely to have larger training responses,[123, 124] whereas those with more experience are likely to have dampened training responses.[123, 124] This is especially true when considering the lack of specificity in the majority of training interventions, as more specific interventions are likely to be needed in those with more training experience to elicit greater responses.[90, 123, 124]

Overall researchers have explored a wide range of age groups across the literature, with most work investigating players aged 18-29 or over 40. There was very little work on youth golfers, with three papers investigating under 18s, but only one of these including players under 16. Further to this, in the older age group (40+), some of the literature included players into their 60s and 70s. However, no papers sought to investigate high-level golfers in the older age groups. This is of note given the growing recognition of physical training for golf, which is leading youth golfers into more frequent engagement in this area. As such, it would be beneficial for research to continue to expand in this area. Furthermore, with professional golfers competing well into middle age and beyond, and significant prize purses in senior tour events, it would be desirable to gather more literature in older age groups but for players competing at high levels.

4.5.2 Golf performance measures

Many of the studies which look into the effects of strength and conditioning programmes on golf performance have used CHS as an outcome measure. CHS seems to be a preferred method of measuring performance with 16 of the 19 papers using CHS. This measure is likely to be well linked to overall golf performance[3] and also one which is highly relevant to intended outcomes of strength and conditioning programmes in golf. It is also a measure which is less likely to be impacted upon by external factors, and as such is a stable measure for use. Distance-related measures such as ball speed and distance are of value, but we must consider that they are also more likely to be influenced by external factors such as the ball, environmental conditions and technical changes. Most studies which used clubhead speed as a measure have found significant improvements over the course of a training programme.

Researchers measured HCP on three occasions,[110, 114, 120] as a sole performance measure in two of those instances[114, 120] in studies ranging from eight to 14 weeks. While HCP is a good measure of golfing ability, as it ultimately identifies the overall golfing score, there are some potential limitations to this approach, especially if used in isolation. Being a measure of overall score and ability, HCP will change with alterations in many areas of the game which may be outside of the remit of the training intervention. For example, technical improvement in an area of the game, changes in equipment or improvements in course management and decision making could all have substantial impacts on HCP. As could changes in weather conditions, the frequency of play and courses which they player visits. This makes the measure quite unstable, especially over such short timeframes.

Measures of shot quality were taken using a launch monitor on three occasions[105, 107, 108] but in none of these instances were improvements seen in the quality of the shot. This could further support the previous discussion on HCP as well as subsequent discussions around other skill-based measures. If improvements are not being demonstrated in shot quality at the club to ball contact, but are in the distance, the interventions are showing effectiveness but not in impacting technical skill level. It is therefore likely that external factors may influence any potential improvements in non-distance/skill-based factors. Where studies do complete measures of skill-based components, it may be beneficial for researchers to incorporate kinematic as well as specific physical measures to attempt to demonstrate how their interventions cause these skill changes through physical training.

Unfortunately, very few research studies conducted to date have successfully quantified kinematic and kinetic changes to the golfer as a result of strength and conditioning. It is fair to say that we can expect clubhead speeds, ball speeds and driving distances to change as a result of resistance training programmes given the findings of the reviewed work. However, the addition of more robust kinematic and kinetic swing data would allow for a more thorough explanation of the potential mechanisms for change behind these well-established measures. Where biomechanical analysis of the swing has occurred, often favourable outcomes have been observed. Lephart et al.[107] collected kinematic data of golfers using their Peak Motus System v.7.0 and additional data two Kistler force plates. They discovered a significant decrease in the pelvic axial rotation value at the top of the backswing, and significant increases in upper torso axial rotational velocity and x-factor velocity, which could likely explain how the strength and conditioning plan had caused increases in clubhead speed. Bull and Bridge[40] also looked into the impact of training on the golfers' kinematics, following a plyometric training programme. They used a Polhemus Liberty electromagnetic tracking system. Unfortunately, no physical strength, flexibility or power measures were taken to prove the effectiveness of the programme over the intervention period. Also, the authors did not record clubhead speed or ball speed. However, they reported increases in maximum x-factor and rate of recoil of the x-factor during the downswing. Peak speed of the lead arm and hand were also shown to increase. While these results indicate possible within swing kinematic changes available as a result of physical training, it is not possible to say whether these changes would result in increased CHS or distance variables. Doan et al.[105] also attempted to measure the change in the golfers swing. However, they chose to pursue a qualitative video analysis of each golfers swing. While a less reliable way of measuring change, they commented on not noticing and consistent trends through the golfers as a result of the programme and went on to comment on some individual golf swing changes. Parker et al.[113] also looked into the effects of their training interventions on a range of kinematic measures, finding possible or likely beneficial effects on all kinematic measures taken except for x-factor. This indicates that a change in kinematics as a result of training are likely to occur. However, the intervention given did not yield meaningful differences in CHS. Despite this, the researchers did report meaningful improvements in distance and ball speed.

There is an apparent lack of work looking into the kinematic and kinetic swing changes which occur as a result of a physical training programme for golfers of any level. Kinematic and kinetic data allow us to understand how the programme influences the athlete in order to attain the higher CHS and distance variables often reported, and the literature would greatly benefit from a further contribution in this area.

Only one study within the current literature has investigated the potential impact of a golf fitness programme on short game and putting. Doan et al.[105]found some significant changes in putting distance control with their male group ($p=0.007$) only post-training, but no significant changes in females ($p=0.709$) or as a total score ($p=0.064$). Studies also explored impacts on trackman combine and total golf performance score.[108, 119] Similar to studies investigating handicap, we should approach both of these measures alongside short game ability and putting[105] with some caution. There are many potential factors which could have more substantial impacts on performance in these areas than training interventions, due to their high skill nature, and we should consider this should when interpreting results.

4.5.3 Physical fitness measures

The evaluation of physical characteristics over the course of a study is valuable in demonstrating the effectiveness of a given intervention. If a training programme has been unable to elicit improvements in previously identified physical characteristics, then the training is unlikely to have been a success and therefore improvements in golf performance may not be present. In these instances, if golf performance improvements are present, they may not be as a result of the intervention. Only two of the 19 papers failed to report any changes in physical characteristics within their work.[40, 115] Of those which did measure physical characteristics, the vast majority saw improvements in some of their chosen measures, demonstrating programme effectiveness. Throughout the 17 studies, researchers used a wide range of measurements, these generally included anthropometrics (primarily body mass), explosive strength, strength/strength endurance, flexibility/range of motion, balance/proprioception and cardiorespiratory fitness. Most common measures of physical performance included measures of strength and explosive strength. Given findings from previous literature relating these characteristics and their relationships with golf performance,[45, 71, 73, 74, 78] their importance and therefore prevalence in the research is not surprising. Measures used to assess these characteristics were often similar to those used in the literature looking into relationships between physical characteristics and golf performance, showing some validity to their inclusion. On 11 occasions research used flexibility outcomes, and most studies included some stretching within their programmes. However, the role of flexibility in determining golf performance is still not clear, with some papers finding positive[4, 84 80 70, 72, 75] and some finding neutral or negative relationships with golf performance.[74, 76, 84, 85, 87] Balance and cardiorespiratory measures were taken less frequently. Neither of these areas is linked to golf performance at this time.[4, 46, 79, 80, 87]

Study lengths varied from six to 18 weeks of training, with the majority around eight weeks. During this length of time, many of the physical changes as a result of training will come through neural adaptations resulting in increased motor unit recruitment and firing patterns.[90] Although some limited improvements in morphology, such as increases in muscle cross-sectional area will be occurring in the longer studies from eight to 18 weeks.[90]

4.5.4 Pre/post interventions

Of the four pre/post studies looking into the effects of training on performance[105-108] all but one saw improvements in CHS and distance variables. However, Oliver et al.[108] reported a 21% dropout rate and only 55% attendance at training sessions, which both could have contributed to these neutral results. Although they did observe increases in some of the musculoskeletal screening tests, demonstrating the programme may have shown effectiveness in modifying some of the players' physical attributes. While results in three of the four studies indicate both physical and golf performance improvements as a result of the training interventions, due to lack of control groups, it is hard to ascertain the direct effect of the independent variable (the training intervention) on the result. Therefore, despite the largely positive findings of these studies, caution should be taken when interpreting these results.

4.5.5 Comparing training against no training

Nine of the 19 papers investigated the effects of a training intervention against a no training control group. Of these, one of the papers failed to compare data statistically between groups.[115] The omission of statistical comparisons between groups makes it difficult to say that the training was adequate, despite the training group showing a 2.1mph increase over the control group. Fletcher and Hartwell[115] also failed to offer measures of physical improvement, meaning that the changes may not be related to specific physical improvements through training, or if they are, it is not possible to identify which physical characteristics improved. In all other cases where researchers used no training control groups, they evaluated the interventions through statistical comparisons between control groups and intervention groups.

In most cases there were improvements in golf performance measures, indicating the beneficial effects of training on performance. The consistent use of CHS in the majority of papers makes a comparison of studies possible, an in most cases improvements were present. However, other than CHS, golf performance outcomes were varied. In the case of Bull and Bridge,[40] the researchers used kinematic measures following a plyometric intervention. While improvements in some kinematic measures related to distance improved, the lack of ball, distance or CHS data does not allow understanding of whether or not these kinematic results transferred to performance outcome. This was also true in the case of Smith et al.[120] when they investigated training in youth golfers. In this case, HCP was used, with no other measures of golf performance. Despite a lack of improvement in HCP, the intervention was only 12-weeks, making HCP a less than ideal choice of dependent variable, and the study failed to take measures of CHS or distance. These were similar findings to Van der Ryst et al.[114] who also only used measures of HCP over a 14-week period and this study may also have benefitted from more specific measures of transfer to performance.

Regarding intervention and controls, approaches across the research were often mixed. Two papers investigated specific plyometric interventions, although, in the case of Bull and Bridge[40] the intervention was primarily ballistic as opposed to plyometrics. Also, while resistance training was given in all other cases, the construction of resistance training interventions varied a great deal. Some papers lacked the detail required to reproduce the interventions,[114] some used lighter load or bodyweight programmes,[116, 118, 120, 121] machine weights[122] with one paper using more traditional heavy loaded work.[115] In instances where investigators used lower load or bodyweight exercises, they were not high-velocity movements, but often high repetition low load exercises. As a result, it is likely that many of the exercise programmes may have been suboptimal as high loads are ideal for improving strength[98] and a blend of intensive explosive and heavy lifting exercises are ideal for improving explosive strength.[125] In many cases, neither of these approaches were utilised. As a result, despite general programmes showing improvements in performance, it is likely that more appropriate training with specific focus' on strength or explosive strength may show greater performance enhancement against non-training control groups. There were also some differences in the detail given around control group activities, with some studies being more explicit than others regarding the exact instructions given and the amount of participation in other activities golfers were involved in. This is an understandably difficult area to control, so efforts should be made to include as much detail as possible.

Overall it appears that strength and conditioning interventions have a generally positive impact on golf performance, primarily through increases in CHS and distance related variables, with some reported improvements in kinematics. Improvements in programme design and implementation in future studies may continue to support these findings, but with larger effect sizes.

4.5.6 Comparing different training interventions

Of the six papers comparing different types of training intervention, two failed to compare data statistically between groups.[111, 119] In the case of Cummings et al.[111] whilst fat grip training led to significant increases in ball speed, carry and drive distance in pre/post testing the lack of statistical comparison to control makes it difficult to support the conclusions in favour of fat grip training. Results demonstrated a reduction of 0.31mph between groups in favour of traditional resistance training. Loock et al.,[119] observed similar issues when comparing bodyweight core and the use of a COREPOWER machine. In this case, both sets of pre/post test results demonstrated training to be effective at improving golf performance. However, no between-group statistical comparisons were made to inform which intervention was optimal.

Four further studies compared different intervention types, using a range of approaches. Two studies[109, 112] compared forms of the lower load against higher load and explosive training, both finding positive results in favour of high load and explosive interventions, which aligns well with non-golf literature.[98, 125] Hegedus et al.[117] compared traditional training against golf-specific training, finding few significant differences between the interventions, and Parker et al.[113] compared isotonic with isokinetic training, finding some possibly likely differences between the interventions, however there was no difference in CHS between groups. Overall these findings seem to indicate higher load, and explosive training is advantageous against lower load training. However, there is a lack of research supporting more specific approaches. In general, due to the wide variety of approaches used so far, it is difficult to draw firm conclusions. Future research may benefit from focusing on refining what is known to work by looking into specific high load strength, explosive strength and mixed methods approach to determine optimal training interventions for golfers.

4.5.7 Study quality

Across the 19 studies reviewed, overall study quality was fair, with only two studies scoring as high quality,[109, 112] 12 of fair quality[40, 110, 113-122] and one of low quality.[111] four papers were not included in the quality assessment due to their pre/post approach as opposed to use of a true control.[105-108]

Common reasons for lower scores were varied but generally related to randomisation, concealment of group allocation, blinding, drop-out/completion rates, amounts of participants who completed interventions and lack of use of intention to treat where appropriate. Given these observations, future research in warm-up should aim to improve quality of work by ensuring a randomisation process where possible, with clearly stated concealment of group allocations, ensuring adequate reporting of participants entering and then participants completing the training interventions as well as completion of intention to treat where appropriate. Researchers may struggle with blinding training intervention studies, given their nature. However, the feasibility should be considered in the design process.

When breaking down studies further, four papers completed pre/post analysis only.[105-108] Nine compared a training intervention against a non-training control,[40, 110, 114-116, 118, 120-122] of which one did not complete between-group statistical analysis.[115] Finally, six compared different types of training interventions,[109, 111-113, 117, 119] of which two did not complete between-group statistical analysis.[111, 119] Most of this literature has demonstrated positive impacts of training for golf in adults, this assessment shows the need for either further comparisons between different training interventions in search of optimal training for an adult golfer, or exploration into specific poorly researched groups, such as youth or high-level senior players.

Overall this quality analysis demonstrates a need for more high-quality studies or research into specific areas needing further investigation rather than general increases in the volume of moderate quality literature in the area. Future research should, therefore, aim to deliver high-quality work, scoring a minimum of 6/10 on the PEDro scale, and should look into specific research gaps, such as training in youth or high-level senior populations. Studies comparing different types of training intervention, with a probable focus towards high intensity heavy or explosive work or with aims of improving lean mass, strength and explosive strength qualities would also be welcome.

4.6 Areas for future development

Although a range of appropriate future research areas exist within this field, there is a clear need for more literature investigating impacts of strength and conditioning in youth golfers as well as elite seniors. Moreover, it seems clear that strength and conditioning is an effective means for performance enhancement, but further work should look to investigate methods to optimise programme design by comparing different training approaches.

4.7 Conclusion

This review demonstrated the particular impact strength and conditioning work has on golf performance. Most likely impacts of training are increases in CHS and distance. However, some researchers have also shown improvements in other, more skill related tasks within the sport. There is a lack of high-quality work investigating the impact of training interventions on youth and elite senior golfers and well as those investigating optimal training methods through comparison of different training methodologies. Despite this, from the available literature, high load and explosive exercises were the most effective training methods when compared to lower load training.

PART ONE SUMMARY

Throughout the systematic reviews in Part One of this thesis, I have identified a common theme. The research into youth golf physical preparation is sparse and in need of growth across all topics. The literature is also lacking with regards to the identification of relationships between physical characteristics of youth golfers and performance, which would inform physical preparation strategies. Therefore, research widening the knowledge of youth strength and conditioning in golf is warranted.

YOUTH TRAINING CONSIDERATIONS

Although the research exploring the role of youth strength and conditioning in golf has remained stagnant, wider growth in youth performance literature is on-going. This growth in literature has led to consensus on the benefits of resistance training for health, sporting performance and injury risk reduction in youth populations.[15-17] The scientific and professional consensus has moved on from previously held negative beliefs around the injury and developmental risks associated with resistance training in youth athletes, as well as questions over their trainability.[15] The research now firmly supports resistance training in youth athletes, with no firm body of evidence supporting high injury rates,[15] and with many studies demonstrating positive responses to training provided appropriate interventions and supervision is present.[15-17]

Research has shown a range of health benefits as a result of resistance training in youth populations. These include improvements in bone health,[126, 127] body composition,[128] insulin sensitivity,[129] psychological wellbeing[130, 131] and the impact on future desirable physical activity behaviours.[132, 133] Not only are a range of health benefits on offer, but also resistance training has been shown to reduce injury risk from sport in youth populations.[20,21]

Several publications have highlighted the impact of resistance training on physical qualities of youth populations,[15-17, 19] with specific evidence supporting increases in muscular strength, explosive strength and sports performance[19], Studies have repeatedly shown increases in strength, explosive strength and sports performance,[19] attributes which seem desirable in youth golfers. When training youth athletes, often an increase in the direct physical qualities such as strength or explosive strength will be larger than those specifically related to the sport, however Lesinski et al.[19] speculate that this is likely to be due to the complexity of sports specific tasks, meaning that more variables will impact the outcome. This statement is likely to be particularly true for golf, where technical and tactical abilities are of high importance. Research into other high-velocity, rotational and explosive batting sports, like golf, have shown transfer of training to performance.[134, 135] As a result, we can expect golfers to positively increase physical characteristics such as strength and explosive strength through training, with likely transfer to golf clubhead speed, as has been found in adults. The ability of training interventions to improve specific characteristics which have been shown to be related to performance in golfers is promising. As is the literature supporting transfer to sports performance. So, despite the lack of direct research evidencing training and its impact on the youth golfer, sufficient evidence supports the use of these methods in similar youth sporting populations and should, therefore, be explored.

The case for warm-up is similar to that of resistance training; researchers have explored impacts across a wide range of sports, often showing benefits in sport specific as well as general physical performance as well as aiding in the reduction of injury risk.[11, 13, 23, 49] Warm-ups have been shown to support the enhancement of explosive activities in youth athletes.[11, 13] while there is a lack of youth literature relating these qualities to youth golf performance, we know that they link with performance in adult golfers and so it is fair to postulate that enhancing these qualities through warm-up is likely to have a transfer to golf performance. As a result, it is reasonable to expect that warm-ups may have performance enhancing properties in youth golfers and are worthy of further study.

Therefore, the subsequent chapters of this thesis will focus on the applications of strength and conditioning practice towards youth golf populations. I address this area of research by answering research questions 2-5, as proposed in section 1.7.

Part Two: Establishing the Impact of Warm-up on Youth Golf Clubhead Speed and Perceived Shot Quality

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"I can go and do a simple warm-up in the gym and I just feel better"

Jordan Spieth

5 CHAPTER FIVE: THE IMPACT OF WARM-UP ON YOUTH GOLFER CLUBHEAD SPEED AND SELF-REPORTED SHOT QUALITY

5.1 CHAPTER OUTLINE

Following on from my findings in Chapter Two, and the subsequent decision to contribute to youth golf literature, I seek to explore impacts of warm-up on CHS and perceived shot quality in youth golfers. Using a counterbalanced repeated measures design, eight male and 13 female youth golfers complete a control, club only warm-up and an exercise based dynamic warm-up followed by club warm-up on three non-consecutive days. I take maximal clubhead speed and self-reported shot quality measures as dependent variables. I observe improvements in clubhead speed and self-reported shot quality in the dynamic warm-up combined with club warm-up. No significant differences are seen in the club-warm up only or control groups for either clubhead speed or self-reported shot quality. Within this chapter I demonstrate the importance of using physical warm-up before playing golf, for its positive impacts on clubhead speed and self-reported shot quality.

This Chapter is organised as follows:

Section 5.2 introduces the underpinning rationale for designing a study which explores the impacts of warm-up on CHS and perceived shot quality in youth golfers.

Section 5.3 presents the methodological approach taken to test the impact of warm-up on CHS and perceived shot quality in youth golfers.

Section 5.4 highlights the results of the research which address the related research questions.

Sections 5.5 onward offers discussion on the knowledge which I created as a result of the study. I also propose areas for future development in this field of research.

5.2 INTRODUCTION

Carrying out a full physical warm-up is a commonly accepted process for enhancing performance and mitigating injury risk across a range of sports.[23, 49, 136] As such, golfers are employing these practices at the elite level, however, there is currently no literature exploring the impact of warm-up on the youth golfer. In adult golfers, completing a warm-up in the form of preparatory dynamic exercises prior to competition has been shown as performance-enhancing through demonstrable improvements in CHS.[8, 57] Moreover, a golf warm-up has been shown to improve driving distance,[9, 57] shot quality,[8, 57] flexibility[9] and power,[9] as well as having a potential conditioning effect when completed regularly,[7] demonstrating the importance of these practices in golf. However, despite the evidence showing positive effects of warm-up in adult golfers, behaviours are less than desirable, with many golfers completing inadequate warm-ups.[51, 137]

Research has demonstrated a need for dynamic rather than static based stretching as part of the warm-up routine. Significant decreases in CHS, driving distance and shot quality has been shown as possible consequences of static stretching immediately prior to golf.[8, 58, 59] These findings are in line with those of other sports, where static stretching has been shown to reduce explosive muscular performance acutely.[64, 138] Use of bodyweight exercises, bands, weights, whole-body vibration and club specific warm-ups have all be shown to have positive effects on performance.[8, 9, 57-59] Evidence also suggests post-activation potentiation through the use of explosive jumps can have a positive impact on CHS and there may be used in incorporating these techniques prior to particularly long shots whilst on the course.[139] The completion of a warm-up in golf may also have potential benefits concerning injury risk reduction.[50] Therefore, encouraging a player to carry out a sufficient, well-planned warm-up successfully seems to be a desirable goal of any coach or therapist.

Despite the evidence supporting the use of warm-up in golf for adult populations, there is no current literature which targets youth populations. Researchers have extensively explored the effect of warm-up on youth athletes outside of golf, often demonstrating positive effects on relevant performance measures[11-13] and a reduction in injury rates.[14] This clearly outlines a need for the inclusion of youth-specific warm-up research within the sport of golf. Moreover, with evidence demonstrating poor warm-up habits in adult golfers,[51, 137] the inclusion of appropriate warm-ups within a youth golfer's routine could be essential in creating positive behaviours towards warm-up at a young age. This will then also allow the golfer to enjoy all the proven benefits associated with this behaviour when they progress to adulthood. Of note, many studies to date have required the use of additional equipment for a warm-up,[9, 57, 59] which may be off-putting or impractical for the youth golfer and reduce compliance. Creation of an evidence base for the youth golfer, especially with regards to warm-up, is essential to inform youth development programmes, coaches, therapists and other associated professionals, so they can best support these aspiring young athletes. Given the lack of research into warm-up in the youth golfer, this study aimed to examine the impact of a club only warm-up and a dynamic exercise routine followed by a club warm-up on CHS and self-reported shot quality.

5.2.1 Research Questions

My purpose within this chapter was to investigate Research Question 2 *'Are clubhead speed and shot quality enhanced through an appropriately designed warm-up in high-level youth* *golfers?'.* I would achieve this purpose by addressing the following Research Objectives, which were to:

- Successfully deliver the warm-up interventions, as demonstrated through dropout rates of no less than 85% and intention to treat analysis where appropriate.

- Demonstrate effectiveness of the interventions through statistical analysis of CHS changes between interventions.

- Demonstrate the effectiveness of the intervention through statistical analysis of changes in shot quality ratings between interventions.

5.2.2 Hypotheses

Relating to Research Question 5 and the associated Research Objectives, the hypotheses were:

- Between-group differences in CHS will favour an exercise based dynamic warm-up when combined with a golf club warm-up over no warm-up or golf club warm-ups alone.
- Between-group differences in CHS will favour a golf club warm-up over no warm-up.
- Between-group differences in self-reported shot quality will favour an exercise based dynamic warm-up when combined with a golf club warm-up over no warm-up or golf club warm-ups alone.
- Between-group differences in self-reported shot quality will favour a golf club warm-up over no warm-up.

5.3 METHODS

5.3.1 Participants

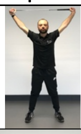
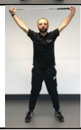
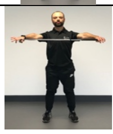
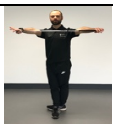
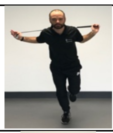
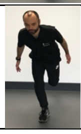
Eight male and 13 female youth golfers (HCP 1.8±2.8 strokes, age 16.6±1.7 years) were recruited to take part in this study. At the time of testing, no golfers were suffering from injuries which impacted their golf. The players and guardians gave informed consent to take part in the study. Players were given a participant information sheet outlining the goals of the work. The University Ethics Committee granted ethical approval. Group allocation was concealed when determining participant eligibility.

5.3.2 Procedures

A counterbalanced repeated measures design was used, with participants randomly assigned to initial groups of either control, club only warm-up, dynamic and club warm-up. Testing was completed by one researcher, outdoors at several locations, using available driving range facilities. Participants completed each testing protocol on separate, non-consecutive days. To obtain CHS values, a TrackMan (ISG Company, Denmark) launch monitor was used. The monitor was calibrated as per manufacturer instructions. Reported accuracy for the Trackman launch monitor is ±1mph and ±2.5mph for clubhead speed on 54% and 87% of occasions respectively.[140] An internal study of test-retest reliability was conducted at the University. Clubhead speed was shown to be highly reliable between testing sessions (r=0.995) with minimal detectable change scores of 1.02mph based on a 1.645 z-score. Further details of the reliability study can be seen in Appendix A.

On the control testing day, golfers were instructed to complete ten maximal drives measured on the TrackMan system. Golfers were allowed to complete a self-defined number of practice swings. Golfers took a one-minute rest between maximal effort swings during testing. Golfers used their drivers and were blinded to their clubhead speed and other values from the launch monitor. Golfers used range balls for testing, in a variety of locations, and so only clubhead speeds were noted, and other metrics, such as ball speed, accuracy and driving distance, were disregarded due to the likely lack of reliability across testing locations. Clubhead speed was determined to be a more robust measure in varying conditions as it was less likely to be impacted upon by ball quality/type and weather conditions. On intervention days, golfers were required to complete either a club warm-up only or an exercise based dynamic warm-up which was immediately followed by the club warm-up (table 5.0). Once the golfers had completed the appropriate intervention, they took ten maximal effort shots, which were measured on the ball launch monitor as per control testing. During all measured shots, golfers also required to give a self-reported shot quality score (0-10), where 0 represented the golfers worst possible shot and 10 was representative of their best possible shot.[141] Both warm-up conditions were developed through modification of the previous literature[57, 59] in consultation with experienced national level golf coaches. The warm-up variations were also developed with no equipment beyond standard golf clubs to enhance the relevance to youth golfers.

Table 5.0: Club and dynamic warm-up routines

Dynamic Warm-up	Start position	End position	Club Warm-up
10x overhead squats			4x shots for 3 different self-selected pitching distances
10x squat to overhead reach			4x full-swing shots with 8 iron
10x (5 on each leg) lunge and side bend			4x full-swing shots with 6 iron
10x (5 on each leg) lunge and rotate			4x full-swing shots with 4 iron
10x (5 on each leg) standing internal hip rotation			4x full-swing shots with 3 iron
10x (5 on each leg) single leg land and rotate			4x full-swing shots with rescue
10x (5 on each leg) lateral bound			4x full-swing shots with 3 wood
Complete all the above twice			4x full-swing shots with driver

5.3.3 Statistical analysis

Statistical analysis was performed using SPSS 23.0 software. A repeated measures ANOVA test using the three sets of mean scores was employed to look for differences between interventions for CHS values. For the shot quality scores, the Friedman and Kendall's W tests were used on three sets of median scores. Finally, these were followed with a Wilcoxon signed ranks test. The significance level was set at $p<0.05$.

5.4 RESULTS

All participants completed all interventions within the experiment. Main findings are shown in table 5.1 and 5.2. There were statistically significant improvements in CHS ($p<0.001$) from a dynamic warm-up combined with a club warm-up, showing a 1.1% increase when compared with control and 0.6% compared to club only. No significant differences were shown between the control and club only warm-up for CHS ($p=0.877$) despite a 0.5% increase in CHS nor between the club only warm-up and dynamic warm-up combined with a club warm-up for CHS ($p=0.385$) despite increases of 0.6%. The Friedman test and subsequent Wilcoxon signed ranks test revealed significant improvements ($p<0.001$) in shot quality scores for the dynamic warm-up combined with a club warm-up when compared with both clubs only warm-up and control, showing 40% improvements in scores, with no significant differences ($p=0.46$) between club only and control.

Table 5.1: CHS and self-reported shot quality following warm-up interventions

	Control	Club	Dynamic	ES	Power
Mean CHS (mph)	92.9±7.9	93.4±7.0	93.9±7.60**	0.63	0.998
Median Shot Quality (/10)	5	5	7**	0.52	-

**Indicates significance ($p<0.001$)

Table 5.2: Mean % difference between different warm-up protocols on dependant variables

	Condition	% change	*p*	95% CI for mean lower-upper
CHS	Club vs. Control.	+0.5	0.877	-0.641 to 1.547
	Dynamic vs. Control.**	+1.1	<0.001	0.545 to 1.520
	Dynamic vs. Club	+0.6	0.385	-0.375 to 1.535
Shot Quality	Control vs. Club	0	0.460	-
	Dynamic vs. Control**	+40	<0.001	-
	Club vs. Dynamic*	+40	0.002	-

*Indicates significance (p<0.05), **Indicates significance (p<0.001)

5.5 DISCUSSION

With no current literature available on the impacts of warm-up on youth golfers, this work is an essential step in expanding the knowledge base and demonstrates the utility of warm-up routines for youth golfers. Although statistically significant effects were shown in favour of the dynamic warm-up over the control group, the 95% confidence interval was only 0.545 to 1.520. Despite the demonstration positive effects, these improvements are likely to be of low impact to real-world golf performance.

Given the limited research on golf warm-up and especially in youth, female, skilful and low handicap players, this research makes a valuable contribution to the body of evidence on physical preparation in golf. With evidence already supporting the use of club warm-ups and exercise based dynamic warm-ups in golf,[8, 57] this investigation looked to apply these principles to the youth golfer, using no equipment beyond golf clubs. The investigation specifically aimed to explore the impact of a club only warm-up and a dynamic exercise routine followed by a club warm-up on youth golf performance, demonstrated through changes in CHS and self-reported shot quality. Given the pragmatic nature of this thesis, a few key decisions were made in order to maximise the potential impact and utility of the work, while accepting inevitable limitations in the process. First, experiments were conducted outdoors with high level youth golfers. This allowed for ecological validity, and access to a greater number of high-level players, who were within the development pathways for whom this research was aimed to impact. However, due to the use of outdoor testing, range balls were used in varying weather conditions, making clubhead speed the only reliable measure. These environmental contraints excluded the use of additional measures of accuracy. As a result, the impact of the warm-up on self-perceived shot quality was used. While not a direct measure of accuracy and swing change, it was feasible in the environment, and due to the high standard of the golfers involved, was also likely to be somewhat reliable. Warm-up approaches were also pragmatic, requiring no more than a usual set of golf clubs. This would ensure that young players/coaches were not required to purchase additional equipment if they wished to use the methods in practice.

The results showed a significant increase in CHS when golfers completed a dynamic exercise routine followed by a club warm-up against a control. However, the changes in CHS were low, so although statistically significant, are likely to have low impacts on real-world performance. Also, changes were just on the previously reported minimum detectable change of the launch monitor, meaning while they are likely to be representative of an improvement, some caution must be taken when interpreting the magnitude of change.

Significant improvements in self-reported shot quality from the dynamic exercise routine followed by a club warm-up were also shown when compared against the control and club only warm up. However, no significant improvements were seen between the club only warm-up and the control.

It is possible to speculate that the improved CHS and perceptions of short quality may have come through a few key physiological changes which would be expected to accompany a warm-up. Improvements in muscular activity,[142] leading to improved intramuscular co-ordination (motor unit synchronisation, recruitment and rate coding) may have led to greater peak torque,[142] resulting in greater force production within swing ground reaction forces, and these increased forces would then be transmitted through the kinematic chain leading to greater momentum at the clubhead.[43, 143] Intermuscular co-ordination may have also improved due to improved muscle activity,[142] helping to enhance timing and kinematic sequencing of the golf swing.[143]. This may have also resulted in more control within the golf swing, leading to improved centredness of strike, thereby improving smash factor and shot accuracy. Also, improvements in flexibility, due to increased muscle temperature and compliance[142, 144, 145] may have allowed for a greater x-factor and x-factor stretch[53, 70], as well as improved comfort in achieving the large ranges of motion required for the golf swing,[43] thereby improving both CHS and perceived shot quality.

The findings from this investigation demonstrate some of the positive impacts of completing a dynamic exercise routine before hitting golf shots in youth golfers. While changes in CHS were low and likely to make minimal improvements to overall performance, there appear to be quite noticeable changes in self-reported shot quality. These improvements in shot quality are likely to result in increased performance confidence and while not measured within this study, may transfer to noticeable improvements in shot outcome. This research also outlines that while club only warm-ups show trends towards improved CHS, they are likely to be insufficient in eliciting the desired CHS and shot quality improvements on their own. We know these findings are in line with previous literature in adults, where dynamic warm-ups have consistently shown enhanced results.[8, 57]

Whilst changes in CHS were significant but low in this study, work in adult golfers has demonstrated larger and more performance relevant improvements in CHS.[8, 57] Research in adult gofers has also demonstrated a lack of positive warm-up behaviour[51, 137] and reductions in injury risk through golf warm-up.[137] As such, despite the relatively low increases in CHS through this warm-up intervention, the demonstration of positive and non-harmful warm-up effects in youth golfers should be sufficient to encourage practitioners to instil positive warm-up behaviours in young golfers. Given the significant and varied positive outcomes when golfers reach adulthood and acknowledging current poor warm-up practices in golf, the implementation of warm-up routines in youth golf should be a desirable goal. This research should aid in encouraging warm-up practices and improving attitudes and behaviour to warm-up of youth golfers.

Given the relative infancy of youth golf warm-up research, there are many areas which are worthy of future investigation. However, based on the current work, logical next steps should include evaluation ball speed, smash factor (CHS to ball speed ratio) and accuracy measures as a result of proper warm-ups. This will aid in determining whether players' perceptions of shot quality are in-line with actual shot quality. This was not possible within the current work due to the variable locations and balls used for the investigation. Moreover, work investigating the most efficient exercises for a warm-up, impacts of warm-up on injury risk reduction and whether regular warm-ups also have a potential conditioning effect for youth golfers would bring the literature more in-line with current adult golf research in preparation for continued expansion.

5.6 Practical Implications

These findings have a direct practical application, clearly demonstrating the small but influential effects of golf warm-up in youth golfers CHS and perceived shot quality. The use of a dynamic exercise-based warm-up followed by a club warm-up would be advisable for youth golfers to make small but meaningful improvements in CHS, enhance self-perceived shot quality and instill positive warm-up behaviours for the future. This paper gives the strength and conditioning coach practical exercise suggestions requiring no additional equipment as well as a club warm-up routine, all of which they can implement immediately.

PART THREE: IDENTIFYING PHYSICAL CHARACTERISTICS WHICH RELATE TO YOUTH GOLF CLUBHEAD SPEED

"After four weeks of tournaments, and it comes down to that last Sunday, I know I'm more physically fit than most"

Brooks Koepka

6 Chapter Six: Physical Characteristics of Youth Elite Golfers and their Relationship with Driver Clubhead Speed

6.1 Chapter Outline

Building on from Chapter Three, and with the aim of developing more high-quality youth golf literature in the area, I seek to investigate the relationships between a range of physical characteristics and clubhead speed in youth golfers. 36 male and 33 female golfers aged 13-17 take part in the study, and a correlational design is used to assess relationships between CHS and anthropometric, strength and power measurements. Findings indicate strong relationships between clubhead speed and body mass as well as upper, lower and whole-body explosive strength. This information goes on to help with the programme design and selection of dependent variables in Chapters Eight and Nine.

This Chapter is organised as follows:

Section 6.2 introduces the underpinning rationale for designing a study which explores the relationships between physical characteristics and CHS in youth golfers.

Section 6.3 presents the methodological approach taken to test the relationships between physical characteristics and CHS in youth golfers.

Section 6.4 highlights the results of the research which address the related research questions.

Section 6.5 onward offers discussion on the knowledge which I have created as a result of the study. I also propose areas for future development of the research in this field.

6.2 INTRODUCTION

To further establish the importance of physical preparation in the game of golf and inform training interventions, it is essential to identify key characteristics associated with increased CHS and maximal ball displacement. Several studies have investigated these relationships, in adult golfers, with a range of approaches. Research has explored the effects of anthropometry, flexibility, balance, cardiorespiratory fitness, strength and power on golf performance,[4, 46, 71, 73, 76, 77, 80, 82, 84, 87] with investigations taking place using both field-based and laboratory-based measures. However, to my knowledge, there is no research investigating the relationships between key physical characteristics and golf performance in youth golfers.

Researchers have reported mixed results regarding the relationships between flexibility, balance, and cardiorespiratory fitness, and golf performance in adults. A study conducted by Keogh et al.[84] reported no significant differences in flexibility between low and high handicap golfers, or in relation to CHS. They also reported low handicap golfers as having a trend for reduced hip internal rotation when compared against the high handicap golfers. The authors speculated that this might be due to the fixed and stable base required to create an optimum torso to pelvic separation at the top of the backswing (X-factor). These findings are also supported by Gordon et al.[76] who found no significant relationship between trunk flexibility and CHS. However, despite this, an important relationship between flexibility and performance has been reported.[4, 76, 77] Currently it is unclear whether balance characteristics are noteworthy, and there has been minimal work in this area. Even so, Sell et al.[4]

demonstrated that highly proficient golfers (HCP<0) displayed a significantly better single leg balance than their less proficient counterparts (HCP<0) when looking at anterior/posterior and medial/lateral ground reaction force. Wells et al.[46] also assessed single leg balance, measuring the total time golfers could balance on one leg. There was a significant relationship between dominant leg balance and greens in regulation (the ability to hit the green in two fewer shots than par) (r=-0.43) and between non-dominant leg balance and average putt distance post chip shot (r=0.50). Finally, concerning cardiorespiratory fitness, a fitter golfer may well be able to tolerate the demands of competition, training and practice more efficiently. However, evidence to support these claims is lacking. Wells et al.[46] observed a significant positive correlation between the Leger multi-test run score and golf performance measures. Wells et al.[46] suggested that these findings do not necessarily reflect the importance of cardiorespiratory fitness for the golfer, but instead demonstrate a cross-training effect from other physical work that a more competitive golfer is likely to undertake as part of their preparation.

Regarding anthropometry and golf performance, Keogh et al.[84] reported no statistically significant correlations between any anthropometric measures and skill/performance level in their adult golfers. However, they did comment on a tendency towards low handicap golfers having larger upper arm and total arm lengths. Conversely, Wells et al.[46] took measures of mass, height, body mass index, arm length and sitting height. Their primary anthropometric findings showed male golfers' ball speed (r=0.61) and carry distance with a driver (r=0.62) as well as greens in regulation (r=0.69) correlated with arm length. Also, they found that ball speed correlated well with body height (r=0.48). Further work by Kawashima et al.[83] concluded that higher-level golfers were heavier and displayed lower body fat percentages.

Read et al.[71] took measures of height and mass, as well as total arm length, but found only weak correlations between CHS and all anthropometric measurements (r=0.30-0.38).

More clarity is available regarding strength and power. Evidence shows clear links between these qualities and both CHS and golfing performance in adult golfers. Sell et al.[4] investigated physical characteristics across three groups, based on playing ability identified through handicap (HCP). The categories used were HCP <0, 1-9, 10-20. Highly proficient golfers (HCP<0) displayed significantly larger hip and torso strength than both the HCP 1-9 and HCP 10-20 groups. The HCP <0 group also demonstrated greater shoulder strength than the HCP 10-20 group, and the HCP 1-9 group also had a significantly greater torso strength than the HCP 10-20 group. Similarly, Keogh et al.[84] found low HCP golfers had a significantly greater golf swing-specific cable woodchop and also tended to display a 30% larger bench press value using 1-RM predictions from 3-6RM test. They also found a significant correlation between golf swing-specific cable woodchop (r=0.71) and CHS as well as a tendency for bench press (r=0.50) and hack squat (r=0.53) to be related to CHS. These findings were also supported by Parchmann & McBride[74] who found a significant correlation (r=0.81) between 1RM squat and CHS.

Read et al.[71] assessed the relationships between field-based strength and power measurements and CHS. There were significant correlations between both seated (r=0.70) and rotational (r=0.63) medicine ball throws with CHS. These were the strongest predictors of CHS. Also, the authors found significant correlations between countermovement vertical jump peak power (r=0.54) and squat jump peak power (r=0.53) with CHS. Lewis et al. [73] investigated similar relationships in PGA professional golfers and found significant correlations between CHS and squat jump (r=0.82) as well as CHS and seated medicine ball throws (r=0.71). However, there was no significant relationship between CHS and rotational medicine ball throws (r=0.57). Moreover, Wells et al.[46] showed a significant relationship between CHS and abdominal muscle endurance, vertical jump, dominant and non-dominant leg vertical jumps, pull-ups and push-ups and grip strength. Gordon et al. [76] also reported significant relationships between chest strength (r=0.69) and total body rotational power (r=0.54) and CHS.

Given the clear links between some physical performance measures and CHS, it seems reasonable to suggest their potential importance for use in training, physical testing and for performance enhancement. At present, there is a lack of clarity over which tests are most relevant for the golfer, given the wide variety of assessment methods within the current literature. Also, despite the evidence suggesting the link between physical qualities and golf performance, I am unaware of any research in youth populations, where talent development and early introductions to appropriate training are likely to start, and where many of these physical characteristics may develop. Moreover, the current golf literature is significantly lacking in work representing the female golfer. Given the sparsity of work in these areas, this study aimed to examine relevant physical characteristics in a population of highly skilled female and male youth golfers, to determine the relationships between their physical qualities and CHS.

6.2.1 Research Questions

My purpose within this chapter was to investigate Research Question 3 *'What physical performance measures are most strongly related to clubhead speed in youth golfers?'*. I would achieve this purpose by addressing the following Research Objectives:

- Appropriately select physical performance measures suitable for youth golfers by consulting the adult golf literature and considering the practicality of delivery to youth golf environments.
- Collect physical performance and golf CHS data from high-level youth golfers.
- Analyse and interpret the findings through correlation analysis.

6.2.2 Hypotheses

Relating to Research Question 4 and the associated Research Objectives, the hypotheses were:

- Strong relationships will exist between CHS and rotation, and seated medicine ball throws as well as peak power for a countermovement.

- Moderate relationships will exist between CHS and countermovement jump height, standing long jump distance and push-up repetitions.

6.3 METHODS

6.3.1 Experimental approach to the problem

A cross-sectional correlation study was conducted in youth golfers to ascertain the relationships between field-based measures of physical performance and CHS. Anthropometric values were also recorded to assess their relationships with CHS. CHS was used as the dependent variable, with age, height, body mass, push-ups, modified pull-ups, countermovement jump, standing long jump, seated and rotational medicine ball throws as the independent variables. Correlations between HCP and CHS were also observed, to see if there was a strong link in young players, as has been shown in previous literature in other golfing populations. All testing was carried out on one day, in a standardised order to ensure consistency of the results. Participants were recruited throughout the country, via county, regional and national golf squads, and testing took place in a variety of locations. As such, local strength and conditioning coaches were recruited to support in taking the appropriate measurements. These coaches were given clear instructions and training on how to complete the testing process to ensure maximum inter-rater reliability. Coaches were sent a document prior to the testing day, outlining all physical testing procedures and were asked to familiarise themselves with these prior to testing. On the day, around 30-40 minutes prior to testing, coaches were shown the testing procedures by the principle researcher, allocated to their individual testing station and then given the opportunity to practice with one another until they were happy with the process.

6.3.2 Participants

36 male and 33 female golfers aged 13-17 years were recruited to take part in this study. All golfers were competing at a high level for their age group, as demonstrated through selection to England national, regional or county squads. Testing took place in the off-season and players were injury free at the time of testing. Informed consent was gained from all golfers and their guardians. The University Ethics Committee granted ethical approval.

6.3.3 Procedures

All testing for a subject was completed in one day and within one session lasting around one hour. All testing was carried out alongside UKSCA/CSCS certified strength and conditioning coaches, who had been trained to deliver the assessment protocol. A standardisation process was completed to ensure maximum inter-rater reliability, although this was not measured. In all tests, golfers completed three trials, and a mean score was taken for statistical analysis. Measurements were taken for height (cm), and body mass (kg) before physical testing. Scales were calibrated before use to ensure accurate measurement. Golfers self-reported their most up to date handicaps.

6.3.4 Clubhead speed

A TrackMan (ISG Company, Denmark) launch monitor was used to record CHS and calibrated per manufacturer recommendations. Once testing began, the golfers were permitted to complete a self-defined number of practice swings and hit balls until they felt ready to begin testing. Once the golfers were ready for testing to commence, they were given the instruction to 'hit the ball as hard as you can, while maintaining control'. Three driver shots were then recorded and allowed golfers to rest between shots for 60 seconds. Golfers used their own drivers and were blinded to their CHS and other values from the launch monitor. Mean values were taken for the three shots. A mix of range balls were used for testing, in a variety of locations, so only CHS was recorded. CHS was deemed to be a more reliable measure in varied conditions because the quality and type of ball, as well as weather conditions, will have less impact on the result. Other metrics, such as ball speed, were not recorded because of an expected lack of reliability between the testing locations.

6.3.5 Countermovement jump (CMJ)

Countermovement vertical jump height was measured per Balsalobre-Fernandez[146] using the MyJump phone app. Golfers were instructed to jump as high as possible, with hands on hips, and to maintain straight legs during the flight phase. Further to this, peak power was calculated using Sayers' equation 2a following previous recommendations.[147] Golfers completed three trials with a 60-second recovery between each.

6.3.6 Standing long jump (SLJ)

A new introduction to the golf literature was the standing long jump. The test had previously been shown to be a valid and reliable test in youth athletes.[148] Golfers were instructed to stand with toes touching a start line. They were required to land and hold the finish position of the jump. Jump length was measured from the start line to the participants' heels. Golfers completed three trials with a 60-second recovery between each.

6.3.7 Seated medicine ball throw (SMBT)

The golfers were required to complete a single arm seated medicine ball throw on both left and right sides. This was used as a measure of upper body power and has previously displayed high test-retest reliability.[149] The golfer was instructed to sit on a chair, with their feet out in front of them and resting on another chair of similar height. The golfer was then required to hold onto a 3kg medicine ball and throw it as far as possible. The throw was coached to be a put action, not an overhead throw. The measure of distance was taken from the front of the chair the subject was sitting on to the ball. Golfers completed three trials with a 60-second recovery between each.

6.3.8 Rotational medicine ball throw (RMBT)

As a measure of rotational power, golfers were required to complete a rotational medicine ball throw for distance. The rotational medicine ball throw has previously been shown to have high test-retest reliability.[76] Using a 3kg medicine ball, the golfers were asked to adopt a golf stance and rotate and throw the ball as far as possible. Feet were required to stay in touch with the floor, but the rear heel could lift and move like in a golf swing to achieve triple extension. The ball was also required to land within a 1.5m corridor. If attempts did not meet these criteria, they were discarded and repeated. Golfers completed three trials with a 60-second recovery between each.

6.3.9 Push-up

Research has previously identified chest strength as an important predictor of CHS[76] and therefore a push-up test was utilised.[149] A push-up was used as opposed to 1-RM bench press due to the mix of training experience in the golfers we were assessing. The method used was described by Negrete et al.[149] and chosen for its high-test retest reliability. To complete the push-up test, the golfers were asked to complete three bouts of push-ups for maximum repetitions over a 15-second test period, with a 45 second rest period between each 15-second bout. Males completed a standard press-up, supporting their body weight on hands and toes, whereas females completed the push up starting on their knees. Golfers began at the top of the push-up, with elbows locked, went through a full range of motion and were required to limit neck/head and trunk movement. We gave verbal encouragement throughout the push-up.

6.3.10 Modified pull-up

A modified pull-up was used as a measure of upper body pulling strength, due to its high-test retest reliability.[149] The modified pull-up was used as opposed to a 1-RM bent over row due to the mix of training experience in the golfers we were assessing. To complete this test, participants were required to adopt a supine position, holding onto a horizontal and fixed bar, with their body extended and feet placed on a weights bench. Males placed their heels on the weights bench, whereas females placed their entire lower leg, just below the knees. The participants began with their arms extended and were required to go through a full range of motion, bending their elbows and bringing their chest up to the bar. As specified, golfers completed a maximal number of modified pull-ups within 15-seconds, with a 45-second recovery between efforts. We gave verbal encouragement throughout the modified pull-up.

6.3.11 Statistical analysis

Descriptive statistics were calculated for all physical performance measures, anthropometric values, age, HCP and CHS. Direction and strength of the relationship between clubhead speed and all variables were assessed using a Pearson Correlation Coefficient. A multiple stepwise linear regression was used to ascertain potential determinants of CHS. The Durbin-Watson test was used to test for autocorrelation in the residuals from the regression analysis. Multicollinearity using variance inflation factor and tolerance was tested for. The significance level was set at $p<0.05$. The statistical analysis was completed for males and females independently. Correlations were deemed to be weak if $r<0.30$, moderate if $r=0.30$-0.50 and strong if >0.50 as previously reported in similar literature.[71]

6.4 RESULTS

Descriptive statistics and correlations across all participants are shown in table 6.0. In males, significant correlations appeared between CHS and HCP, SMBTL, SMBTR, RMBTL, RMBTR. Other significant relationships were seen within the correlations but were all only moderate ($r=0.30$-0.50). From the multiple linear regression analysis, the RMBTL explained 71% of the variance, which increased to 77% when also including SMBTL into the model.

With regards to females, significant correlations appeared between CHS and HCP, body mass, CMJ power, RMBTL, RMBTR. Other significant relationships were seen within the correlations but were all only moderate ($r=0.30$-0.50) or weak ($r\leq0.30$). From the multiple linear regression analysis, the golfers' body mass explained 72% of the variance, which increased to 80% with the RMBTR. 84% of the variance was explained by including body mass, RMBTR and height into the model. There were no signs of multicollinearity in any of the above models.

Table 6.0 Descriptive statistics and correlations for male and female golfers

	Males					Females				
	Min	Max	Mean	SD	*r*	Min	Max	Mean	SD	*r*
CHS (mph)	85.3	117.8	104.8	7.5		75.9	105.9	89.3	6.1	
Age (years)	14.0	17.0	15.1	0.8	0.35†*	13.0	17.0	15.1	1.1	0.17*
Mass (kg)	51.7	88.0	68.6	8.5	0.41†**	42.0	84.6	57.3	10.0	0.72‡**
Height (cm)	163.5	196.0	176.7	7.1	0.44†**	152.0	177.0	167.4	5.8	0.35†*
HCP	-3.0	5.4	1.8	2.4	-0.50†**	-3.0	12.6	4.0	3.9	-0.52‡**
CMJ (cm)	16.3	49.7	32.5	8.0	0.11	15.0	46.6	30.8	7.2	0.02
CMJ Power (W)	1527.5	3910.3	3027.8	511.8	0.41†**	1460.9	3573.6	2411.8	562.7	0.60‡**
SLJ (m)	1.7	2.5	2.1	0.2	0.23	1.4	2.3	1.7	0.2	-0.28
SMBTL (m)	2.8	5.6	3.9	0.8	0.67‡**	1.4	4.6	2.8	0.7	0.35†*
SMBTR (m)	3.2	6.7	4.5	1.0	0.61‡**	1.9	4.8	3.1	0.6	0.28
RMBTL (m)	5.4	11.7	8.2	1.8	0.71‡**	3.9	8.7	5.5	1.1	0.57‡**
RMBTR (m)	2.5	11.7	8.3	1.9	0.62‡**	3.7	7.7	5.5	1.0	0.56‡**
Push-up	0.0	21.3	10.0	4.4	0.26	0.0	16.0	8.3	4.4	0.20
Modified pull-up	0.0	14.3	9.0	4.2	-0.22	0.0	11.3	5.4	4.2	0.06

† Moderate correlation(r=0.3-0.5) ‡ Strong correlation (r>0.5) *Correlations to CHS significant to $P<0.05$ ** Correlations to CHS significant to $P<0.01$

6.5 Discussion

Owing to an absence of evidence concerning the youth golf athlete in general, and specifically, about physical characteristics and their relationships with CHS, strength and conditioning professionals lack appropriate guidance around programme design and physical testing in these populations. Moreover, despite a growing focus on CHS, driving distance and overall physicality in the sport, there is currently no research on physical characteristics in youth golfers, which could have potential uses in talent development programmes. The current study, therefore, reports valuable relationships between measures of strength/power, height and mass, which all have practical implications to inform programme design and physical testing procedures in youth golfers, which had previously been unexplored. Furthermore, the current golf literature has a sparsity of research dedicated to the female athlete, and therefore the sex differences demonstrated within this work will have great beneficial effects on growing the knowledge base in this area. Given the pragmatic nature of this thesis, a few key decisions were made in order to maximise the potential impact and utility of the work. Mainly through the use of testing methods which were reproducible in the field, while still maintaining high reliability. These decisions included; the use jump height and calculated peak power, as opposed to impulse or power measured through force plates; use of push-up and pull-up strength endurance testing rather than 1-RM testing for strength; use of medicine ball throws for distance as opposed to velocity measurement through wearables. These choices were made to ensure the tests were feasible for use by coaches and players without access to costly or sophisticated gym equipment, and therefore increase the chance of practical uptake of key testing measurements.

Overall, the results of this study indicate that there were significant relationships between several physical characteristics related to strength and power in high-level youth golfers. High correlations were observed between CHS and explosive throw performances such as RMBT and SMBT. Also, there were moderate correlations between CHS and explosive lower body measurements, such as CMJ power. This work also highlights the relevance of anthropometric characteristics such as height and mass in youth golfers, where reported moderate to high correlations with CHS were seen.

Males showed strong relationships between CHS and upper body and whole-body power production, where RMBTL and SMBTL had highly significant relationships with CHS, explaining 77% of the variance. While body mass only showed a moderate correlation with CHS in male golfers (r=0.41), for female golfers, body mass appears to be a key predictor, explaining 72% of the variance alone, which raised to 80% when also including RMBTR. These findings suggest that there are some similarities and differences between sexes in the relationship between CHS and specific physical characteristics in youth golfers. Similarities include the importance of explosive concentric dominant exercises in young golfers, and in both cases, some importance is placed on body mass and its relationship with CHS. However, body mass is of much greater significance in young female golfers, and due to the importance of CHS in golfing proficiency,[3] could be an important predictor of performance. Moreover, given the relationship between CHS and mass in both male and females, the use of hypertrophy training may be an appropriate intervention to enhance fat-free mass. Interestingly, push-ups nor modified pull-ups were shown to have a meaningful relationship with CHS. This may be because these tests were assessing muscular endurance as opposed to upper body strength or power.

The current study highlights the importance of explosive power-based tests such as medicine ball throws and jump tests. These findings agree with other research into adult populations, which show that a combination of a squat jump and seated medicine ball throw, can explain 49% of the variance in CHS.[71] Whilst age showed a weak relationship with CHS it is not possible to fully distinguish relationships with CHS and mass from development/maturation, and physical advantage may come through maturity as well as specific physical characteristics. It may be that physically mature players possess an advantage in the sport of golf at younger ages, meaning that the impact of relative age effects may be worthy of further investigation in golf. CMJ height was not found to be significantly related to CHS. However, CMJ power was significantly related to CHS. This finding could be present because players with a higher mass will produce greater force and power for the same jump height as those with lower mass. As such, for the professional working with youth golfers, it is important to calculate CMJ power as opposed to looking at jump height alone.

It is possible to postulate over potential mechanisms which underpin the relationships observed, particularly in regard to the apparent importance of body mass, countermovement jump peak power, and medicine ball throw distance. If a golfer has a high lean body mass it could indicate increased muscle cross sectional area, which has a role to play in force production.[91, 150] So a golfer with a large muscle cross sectional area in their lower limbs will be able to generate greater ground reaction forces, leading to improved clubhead speed.[43] The downswing of a golf drive takes between 284ms and 377ms[143], with high skill golfer initiating the movement from the ground up[151] and requiring high ground reaction forces to be produced in this short time[43]. A countermovement jump takes over 250ms to complete,[152] and peak power during a countermovement jump is a measure of ground up force production in the lower limbs. Therefore, the relationship between clubhead speed and countermovement jump peak power is logical due to the similarity of movement, timing and force production. Regarding rotational medicine ball throws, these demonstrate the golfer's ability to generate forces ground up and transmit them through their kinematic chain, as they would in a golf swing,[143] but with a loaded implement. Therefore, the co-coordinative specificity alongside timeframes and whole-body requirements are similar. Whereas the seated medicine ball throw is more upper limb specific. During the golf swing, the upper limbs are required to operate at relatively high velocities compared to the lower limbs,[143] so the seated medicine ball throws offer a measure of upper limb explosive strength which is velocity specific to the golf swing and therefore likely to retain similarity of coordination. As a result, it is quite logical the observed relationships exist, and they also offer a range of potential avenues for the design and implementation of training interventions.

Future research should investigate the correlations between strength-related metrics such as the isometric mid-thigh pull, to determine the relationship between maximal lower body force production and CHS in youth golfers building on previous work,[81] as well as mobility of the hip and trunk.[153] Moreover, investigation into the relationships between fat-free mass and CHS would be a useful addition to the research given the findings of this study. Additionally, using the findings from this study to inform training interventions focused on increased lower, upper and full body power development with a focus on enhancing throw and jump performance as well as programmes designed to increase fat-free mass may be beneficial. Given the findings from this study, specific research into the use of medicine ball throws as a training intervention to enhance CHS may be of interest. This may be valuable work given previous findings showing favourable outcomes in sports requiring high rotational power.[154, 155] Finally, investigations into relative age effects in youth golfers may be of interest, specifically looking at handicaps and squad selections in youth golfers' against their dates of birth relative to the sporting season. This may be of interest given the significant relationships described in this current study between physical characteristics and CHS in youth golfers.

6.6 Practical applications

In this study, I have identified a range of field-based tests related to youth golf CHS. These tests can be used by the strength and conditioning professional in an applied setting as performance measures when prescribing training interventions for youth athletes.

Furthermore, the identification of highly relevant explosive concentric power-based exercises, including medicine ball throws and jumps could be used to inform programme design when working with a youth golfer. This study also demonstrates the importance of body mass as an indicator of golf CHS, which could bring attention towards the potential addition of hypertrophy work at relevant stages within a golf strength and conditioning.

PART FOUR: ESTABLISHING THE IMPACT OF RESISTANCE TRAINING ON YOUTH GOLF CLUBHEAD SPEED AND BALL SPEED

"If you take the top 50 in the world, you're not going to find anyone in there that doesn't have a very strong training regimen"

Dustin Johnson

7 CHAPTER SEVEN: THE EFFECT OF A 12-WEEK RESISTANCE TRAINING PROGRAMME ON YOUTH GOLF CLUBHEAD SPEED AND BALL SPEED

7.1 CHAPTER OUTLINE

In a view to advance findings from Chapter Four by adding more youth literature in this area, and with insights gathered in Chapter Six, I design an interventional study to test the impact of youth resistance training on clubhead and ball speed. I use a quasi-experimental design and assigned 39 male golfers aged 11-17 years either an intervention or control group. A strength and conditioning coach then delivers a 12-week resistance training programme to the intervention group, and improvements in clubhead speed, ball speed, body mass, countermovement jump height and predicted power, as well as modified pull-ups, are tracked as dependent variables. After 12-weeks, the study demonstrates that increases in explosive strength, mass, clubhead speed and ball speed are possible through a once-weekly resistance training programme for youth golfers.

This Chapter is organised as follows:

Section 7.2 gives a brief overview of some influential youth literature which was given due consideration in the design and implementation of the studies in Part Four.

Section 7.3 introduces the underpinning rationale for designing a study which explores the impact of resistance training on youth golf CHS and BS.

Section 7.4 presents the methodological approach taken to test the impact of resistance training on youth golf CHS and BS.

Section 7.5 highlights the results of the research which address the related research questions.

Section 7.6 onward offers discussion on the knowledge which I have created as a result of the study. I also go on to present areas for future development of the research.

7.2 CONSIDERATIONS REGARDING RELATED WORK

There was a need to consult the current youth strength and conditioning literature when designing a resistance training programme for youth golfers, which lead to some key considerations in the study design. These include decisions around training frequency, intensity, volume, rest periods and specific exercise selections. A range of position statements have given specific guidelines around these factors, with supporting evidence to accompany them.[15-17] However, in many cases there was limited available evidence to support the creation of particular aspects of the guidelines, such as frequency of training. Lesinski et al. (2016)[19] conducted a meta-analysis on the effects of resistance training as well as dose-response in youth athletes. Throughout this paper, which included 43 studies, a detailed evaluation of specific programming considerations took place. As such, building on the guidelines discussed previously, Lesinski et al.[19] were able to supply a more robust set of data for decision making. In their work, contrary to the guidelines previously offered, the impacts of training frequency did not seem to impact performance outcome. Training intensities of 80-89% 1-RM were shown to be more effective at eliciting strength gains than lower intensities. During resistance training, five sets were shown to increase muscle strength, whereas three sets were more effective at increasing explosive strength (measured using countermovement jump). For resistance training, 6-8 repetitions were shown to be optimal for improving strength. Lesinski et al.[19] also identified three to four-minute rests as optimal for improving muscle strength. Some of this information is not in precise alignment with the position statements; however, there is general agreement that higher loads, lower repetitions, more sets and more extended rest periods are likely to be ideal for eliciting training responses in youth populations. However, in all cases, the individual and their level of competency will dictate how they progress to this level of training. Moreover, it is worth considering that training should be a continuous process undergoing appropriate change[19] therefore we should consider resistance training to be an 'off-season' activity for golfers due to the principle of detraining. For the reader interested in more extensive coverage of the youth literature, the following is recommended.[15-17, 19, 156]

7.3 Introduction

With a growing demand for physical preparation of golfers, national governing bodies and youth golf training environments are beginning to adopt strength and conditioning into their programmes.[88] However, while there is a growing body of literature on physical preparation in golf, the research around youth golf strength and conditioning is extremely limited.

Several studies have looked to investigate the relationships between key physical characteristics with clubhead velocity and associated golf specific performance measures.[4, 71, 157 73 76, 77, 80-82, 87] To my knowledge, only one study has investigated these relationships in youth golfers.[157] This study was presented in the previous chapter, and demonstrated strong, significant relationships between clubhead speed (CHS) and handicap (HCP) in youth male (r=-0.50) and female (r=-0.52) golfers, demonstrating a link between CHS and ability level.

Moreover, Chapter Six demonstrated significant and strong relationships between body mass, as well as concentric dominant explosive strength tests including countermovement jumps, rotational and seated medicine ball throws. Interestingly countermovement jumps were only related to CHS when peak power was calculated, perhaps due to the relevance of mass, and push-up and modified pull-ups were not related to CHS. These findings are similar to those in adult golf populations, where researchers have shown similar relationships have between CHS and countermovement jump, as well as medicine ball throw performance.[45, 71, 73]

Research into strength and conditioning interventions in the adult golfer have consistently demonstrated positive outcomes relating to CHS, ball launch conditions kinematic, kinetic variables and other performance measures.[2, 48] However, despite a plethora of evidence endorsing strength and conditioning in youth athletes,[15-17] the current research pertaining specifically to youth golfer via interventional research is limited, with only one study to date investigating this area.[120] This study investigated the effects of a 12-week intervention on junior golfers between the ages of 12-18 years. The intervention consisted of both mobility and resistance training, in-line with previous recommendations.[15-17] The training programme resulted in moderate to large effect size differences in measures of strength (single leg squat, side bridge and modified push-ups), as well as improvements in handicap, and no detriments to flexibility. While this study highlights the potential benefits of resistance training for youth golfers, there were some key limitations. The authors highlighted that the study was somewhat underpowered and therefore could not detect significant changes in handicap. Also, handicap is a performance measure which has many contributing variables outside of golfer physicality and is likely to be easily influenced by a range of factors over 12 weeks. Determining factors are multi-faceted and could include golf specific skills such as putting and short game as well as tactics and decision making, weather conditions, illness, course condition and competitions/courses played.

There is a strong evidence base supporting strength-based intervention in youth athletic populations across a range of sports, demonstrating clear benefits to performance and injury risk reduction as well as long-term health outcomes.[15] Therefore, we need an equivalent level of understanding for the youth golfer. Current research demonstrates relationships between positive physical characteristics and golf performance, as well as the potential effectiveness of strength and conditioning in enhancing performance in adult populations. Also, a recent publication has demonstrated the implementation of youth golf strength and conditioning programmes by a national governing body of the sport.[88] There has been research, albeit limited, demonstrating the link between positive physical characteristics and CHS in high-level youth golfers[157] and there are some early indications, through an intervention study, that strength and conditioning may benefit the youth golfer.[120] The aim of this study was to investigate the effects of a once weekly, 12-week resistance training intervention on youth golfers CHS, ball speed and physical performance characteristics.

7.3.1 Research Questions

My purpose within this chapter was to investigate Research Question 4 *'Does resistance training, focused on developing strength and explosive strength, result in greater physical and performance and golf CHS and BS outcomes than no training in youth golfers?'*. I would achieve this purpose by addressing the following Research Objectives:

- Successfully deliver the training interventions, as demonstrated completion rates of no less than 85%, attendance rates for those completing at above 85% and through intention to treat analysis where appropriate.

- Demonstrate effectiveness of the intervention through statistical analysis of appropriate physical performance characteristics.

- Demonstrate the effectiveness of the intervention through statistical analysis of the golf CHS and BS measures.

7.3.2 Hypotheses

Relating to Research Question 4 and the associated Research Objectives, the hypotheses were:

- Between-group differences in body mass, countermovement jump peak power and modified pull-up would show meaningful improvements in favour of resistance training.
- Between-group differences in CHS and ball speed would show a meaningful improvement in favour of resistance training.

7.4 METHODS

7.4.1 Experimental approach to the problem

A quasi-experimental study design was conducted to ascertain the impact of a resistance training programme on CHS, ball speed and physical characteristics in youth golfers. Two groups, control and experimental, performed a pre and post intervention field-based testing battery. During the 12-week intervention, the control group continued their regular golf training regime, while the training group also continued regular golf regime but had an additional one-hour coached resistance training session per week. Local strength and conditioning coaches were recruited to support in taking the appropriate measurements.

These coaches were given clear instructions and training on how to complete the testing process to ensure maximum inter-rater reliability. Coaches were sent a document prior to the testing day, outlining all physical testing procedures and were asked to familiarise themselves with these prior to testing. On the day, around 30-40 minutes prior to testing, coaches were shown the testing procedures by the principle researcher, allocated to their individual testing station and then given the opportunity to practice with one another until they were happy with the process.

7.4.2 Participants

39 male golfers aged 11-17 years were recruited to take part in this study (age: 13.54±1.10 yrs., mass: 59.68±13.10 kg, height: 169.05±7.97, HCP: 10.26±4.67 strokes). All golfers were competing at a high level for their age group, as demonstrated through selection to an English county squad. The intervention took place over the off-season and players were injury free at the commencement of the study. Informed consent was gained from all golfers and their guardians. The University Ethics Committee granted ethical approval for this protocol involving human participants per The Declaration of Helsinki. Group allocation was concealed when determining participant eligibility.

All participants were members of the same county golf union and were likely to have similar practice and competition schedules. Testing took place over the off-season where there were likely to be reductions in golf volume. Convenience sampling was used to allocate participants into the training (n=24) or control (n=15) groups, based upon proximity to the training location and availability to train on the appropriate day. The Moore-2 maturity offset equation was used to calculate maturity offset by group (training: 0.08 yrs, control: 0.57 yrs).

[158] This equation was used as a method of ensuring the groups maturity were not different at baseline, given previous research demonstrating youth athletes post peak height velocity (PHV) are likely to respond more favorably to resistance training.[159] The Moore-2 equation has been shown to be a valid measure of maturity offset, especially in adolescents near PHV.[158] The equation also allows for calculation of maturity offset using only age and stature, making it a simple calculation without the need for additional measurement in what would be a time limited data collection opportunity. The standard error of the Moore-2 equation is 0.542 years, so there was no meaningful difference in maturity between groups.

7.4.3 Clubhead speed and ball speed

An ES14 (Ernest Sports, USA) launch monitor was used to record CHS and ball speed and the system was calibrated per manufacturer recommendations. Golfers used their own driver and were blinded to all results throughout testing. Titleist ProV1 golf balls were used for all shots. Shots were carried out on a golf mat and into a golf net on all occasions, to ensure a stable environment for testing. Golfers were permitted to complete a self-defined number of practice swings and hit balls until they felt ready to begin testing. Once ready, golfers were instructed to 'hit the ball as hard as you can'. Golfers took three driver shots, with a 60-second rest between shots. Manufacturer reported accuracy for the ES14 Pro for clubhead speed and ball speed are ±4mph and ±2mph respectively. Separate to this study, test-retest reliability was evaluated using the methods described above over 2 separate testing sessions. Clubhead speed and ball speed were shown to be highly reliable between testing sessions (r=0.99) with minimal detectable change scores of 1.48mph for clubhead speed and 2.12mph for ball speed based on a 1.645 z-score, further details of the reliability study can be seen in Appendix A.

7.4.4 Countermovement jump

Countermovement vertical jump height was used and was conducted per Balsalobre-Fernandez[146] using the MyJump phone app, which has shown good validity in comparison to a force platform. Peak power was also calculated using previous recommendations,[147] which have previously been shown to relate to CHS in high-level youth golfers.[157] Golfers were instructed to jump as high as possible, with hands on hips, and to maintain straight legs during the flight phase. Golfers completed three trials with a 60-second recovery between each.

7.4.5 Modified pull-up

A modified pull-up was chosen as a measure of upper body pulling strength, due to its high-test retest reliability.[149] while my previous research has shown no significant relationship between the modified pull-up and CHS,[157], the measure was chosen as a low-skill general test of upper body strength to assess the impact of the training intervention. This test was therefore not chosen because of its relationship to golf performance, but to demonstrate the impact of the training programme on upper body strength. To complete the modified pull-up, golfers were required to adopt a supine position, holding onto a horizontal and fixed bar, with their body extended and heels placed on a weights bench. The golfers began with their arms extended and were required to go through a full range of motion, flexing their elbows and bringing their chest up to the bar. Golfers completed three trials of a maximal number of modified pull-ups within 15-seconds, with a 45-second recovery between efforts. Verbal encouragement was given throughout the modified pull-up.

7.4.6 Training intervention

Golfers allocated to the training group completed a one-hour resistance training session once per week. This training dose was selected following a survey of parents and players to ascertain a realistic and longer-term sustainable commitment to the programme and to ensure maximal compliance. Golfers were then split into one of two training groups to ensure appropriate group sizes to maintain coaching quality.

Training sessions consisted of approximately 5-10 minutes of dynamic warm-up, 40 minutes of resistance training and 5-10 minutes of conditioning activities. A pragmatic approach was taken to the resistance training intervention, using expert coaching from a qualified professional to meet the needs of the group (see table 7.0). While we tailored the training approach to individual needs and applied expert local knowledge, the training sessions were designed with youth resistance training guidelines in mind.[15-17]

Table 7.0: Resistance training programme outline

Phase	Method (progression based on technical competency and capacity)	Description	Sets/Reps/ Rest (mins)	Typical coached lifts/exercises (modified to individual need, no more than 5-6 exercises per session)
1	Introduction to resistance training	Introduction to basic exercises and movement patterns	1-2/8-12/<1	Squat, press-up, modified pull-up, hinge, plank/other trunk
2	Bodyweight and soft resistance training	Development of movement patterns into structured exercise. Adding soft resistance (bands, dumbbells, kettlebells, suspension trainers)	2-4/6-12/<1	Goblet squat, press-up, modified pull-up, kettlebell (KB) Romanian deadlift (RDL), plank/KB loaded carries
3	Introduction to barbell training	Continuation of bodyweight work, but with an introduction of barbell lifts and technical coaching with low-moderate resistance	3-6/5-8/2-3	Barbell (BB) back/front squat, BB overhead press, BB bench press, BB row, BB/hex bar deadlift/RDL, KB loaded carries, medicine ball throws
4	Barbell progressions	Building on barbell lifts by applying additional load and working at moderate-higher resistance with technical mastery.	2-5/2-5/2-5	Barbell (BB) back/front squat/jump squat, BB overhead press, BB bench press, BB row, BB/hex bar deadlift/RDL, hex bar jumps, KB loaded carries, medicine ball throws

7.4.7 Statistical analysis

Data are reported data as mean±SD. All outcomes are expressed as the value with 90% confidence intervals. These values are given as both absolute data and standardised data. Standardised data were calculated using Hedges' g to give the measure of effect size. Threshold values for each dependent variable were carefully considered to ensure practical impact. Ball speed was given the threshold value of 4mph and CHS a threshold of 3mph as this is the likely degree of change required to elicit a 10-yard increase in driving distance.[160] A 10-yard improvement would result in a golfer being able to select a different club on their second shot and therefore give them a more desirable option, this was deemed as practically meaningful and confirmed through discussions with national coaches. These CHS and BS thresholds also sat within the test-retest reliability values previously reported. Mass and CMJ height were given threshold values of 2.4 kg and 1.5 cm respectively to demonstrate the effectiveness of the intervention in comparison to previous work with a similar group and training approach.[161] These values were calculated as comparable percentage changes from baseline scores. An increase of 200W predicted jump power was used as a threshold based on the mass and CMJ height thresholds. A minimum detectable change of 2 repetitions was identified in previous work,[149] and was therefore used as the threshold for this score.

Magnitude-based inferences were determined using methods previously described.[162, 163] All inferences were based on the thresholds above. The chance of the difference being positive, trivial or negative and allocation of subjective descriptors were based on the following scale: 1%, almost certainly not; 1–5%, very unlikely; 5–25%, unlikely; 25–75%, possible; 75–95%, likely; 95–99%, very likely; and 99%, almost certainly. Magnitude of effects were classified mechanistically, where if the 90% confidence limit crossed thresholds of the smallest positive and negative effects, the effect was 'unclear'.[163]

7.5 RESULTS

Intraclass correlation coefficients have shown key descriptive statistics, mean changes, effect sizes, confidence intervals and subjective descriptors in tables 7.1, 7.2 and 7.3. All included golfers completed the study. The training group achieved 93% attendance, with each player missing an average of less than one session of the 12 available.

Based on the pre-determined threshold values, results suggested the 12-week intervention was likely to improve CHS (4.25mph; CI90 1.79 to 6.71) with possible improvements in ball speed (4.09mph; CI90 0.78 to 7.40). Possible improvements were observed in mass (2.46kg; CI90 1.55 to 3.36), and likely improvements in CMJ height (3.31cm; CI90 1.23 to 5.40) and predicted power (308.35W; CI90 176.97 to 439.73), indicating the programme had the desired training impact and enhanced my previously identified physical characteristics related to CHS in youth golfers.[157]

Table 7.1: Intraclass correlation coefficients for dependent variables

Test	ICC
CHS	r=0.99
Ball speed	r=0.96
Countermovement jump	r=0.98
Modified pull-up	r=0.93

Table 7.2: Effects of 12-week intervention on CHS, ball speed and physical characteristics (descriptive changes in group results)

Variable	Control baseline	Training baseline	Control post	Training post
Age (yrs)	13.9 ± 1.1	13.3 ± 1.0	-	-
Height (cm)	171 ± 8.4	167.8 ± 7.6	-	-
HCP (strokes)	8.7 ± 3.6	11.3 ± 5.1	-	-
CHS (mph)	98.6 ± 10.0	91.1 ± 7.7	96.6 ± 11.0	93.4 ± 8.2
Ball Speed (mph)	139.9 ± 14.9	126.6 ± 10.6	139.8 ± 15.5	130.6 ± 11.6
Mass (kg)	65.0± 14.3	56.4 ± 11.4	65.6 ± 14.7	59.4 ± 11.6
CMJ height (cm)	25.9 ± 5.6	24.2 ± 6.3	25.9 ± 5.9	27.6 ± 5.7
CMJ pred. power (W)	2459.7 ± 700	1966.3 ± 469.8	2491.5 ± 750.9	2306.5 ± 535

Table 7.3: Effects of 12-week intervention on CHS, ball speed and physical characteristics (confidence intervals and magnitude-based inferences, standardised using effect sizes)

Variable	Minimum important change thresholds (standardised value)	Δ difference between control/training (90% CI)	Standardised Δ difference between control/training (90% CI)	Chances of effect better/trivial/worse (based on thresholds)	Subjective descriptors
CHS (mph)	3 (0.68)	4.25 (1.79 to 6.71)	0.96 (0.40-1.51)	80/20/0	Likely +ve
Ball Speed (mph)	4 (0.67)	4.09 (0.78 to 7.40)	0.69 (0.13 to 1.24)	52/48/0	Possibly +ve
Mass (kg)	2.4 (1.48)	2.46 (1.55 to 3.36)	1.51 (0.95 to 2.07)	53/47/0	Possibly +ve
CMJ height (cm)	1.5 (0.40)	3.31 (1.23 to 5.40)	0.88 (0.33 to 1.44)	92/8/0	Likely +ve
CMJ pred. power (W)	200 (0.85)	308.35 (176.97 to 439.73)	1.30 (0.75 to 1.86)	93/7/0	Likely +ve
Modified pull-up (repetitions)	2 (0.78)	1.65 (0.24 to 3.07)	0.65 (0.09 to 1.20)	34/66/0	Possibly trivial

7.6 Discussion

The purpose of this study was to investigate the effects of a once-weekly resistance training session over a 12-week period on youth golfer CHS and ball speed as well as measures of strength and power compared to a no training group. The results from this study have demonstrated that the sessions could augment performance by showing likely increases in CHS (CI90 1.79 to 6.71mph) and possible increases in ball speed (CI90 0.78 to 7.40mph) because of the intervention. There appeared to be no notable difference in the quality of strike, as indicated through the conversion of CHS to ball speed in either group. Showing no reduction or enhancement of technical proficiency as a result of the intervention. This study has also shown that the training intervention could elicit meaningful improvements in measures of CMJ height (CI90 1.23 to 5.40cm), CMJ predicted power (CI90 176.97 to 439.73W) and mass (CI90 0.95 to 2.07kg), which highlights the effectiveness of the intervention. These findings are not only useful in supporting the effects of resistance training on youth golfers, but also in supporting a once-weekly dose of resistance training in youth athletes. Given the pragmatic nature of this thesis, a few key decisions were made in order to maximise the potential impact and utility of the work. Firstly, the approach was designed to address specific practice needs. As outlined in initial thesis motivations, there was a lack of youth resistance training literature in golf, and this work looked to bridge the practice-research gap. To do this, a simple approach was taken, which was realistic and fell within the normal limitations of the likely practical environments the work was aimed at. Simple programmes were used, which were not overly prescriptive or controlled. This allowed for a more realistic training approach. As opposed to the use of strict and controlled set, repetition, rest, load and exercise selections which may not suit the needs of individuals. Programmes were delivered once weekly, which were realistic and appropriate training frequencies for players and parents to commit to, and therefore would improve retention in the study, but also the ability for replication in practice. Measures of physical and golf performance were kept limited. The use of clubhead speed and ball speed were used to meet the interests of the key stakeholders, while keeping feasible methodology. Simple physical markers were used in line with the work in previous chapters, to ensure testing methods could be replicated in practice. No specialist equipment outside of that found in normal gyms were used, to ensure practitioners could deliver a similar intervention. While golf practice volumes were not monitored, the study took place in the off-season and were likely to be lower.

The findings from this study demonstrated similar changes to CHS as seen with interventions in adult golfers which have shown improvements of between 1.5 to 9.5%.[2] At a 2% increase in CHS for the training group the results from this study showed larger changes in CHS than the 1.5%[115] and 1.6%[105] improvements found in the younger and more skilful groups of adult golfers. To the authors' knowledge, only one other study has investigated the effects of strength and conditioning interventions in youth golfers under 17 years of age.[120] However, the result of the present study are not comparable due to the different approaches in the measurement of performance improvements.

The findings from this investigation have also shown the effectiveness of the 12-week intervention for enhancing general athletic qualities in youth athletes, having elicited similar responses in mass and CMJ height to youth athletes training similarly, but twice per week.[161] This highlights the utility of a once-weekly dose of resistance training in the preparation of youth athletes. Further to this, the intervention showed a trivial increase in modified pull-ups (CI90 0.24 to 3.07 reps) against a threshold of two repetitions.[149] It was also noticeable that the mean difference in CHS (4.25mph) and ball speed (4.09mph) was not only achieved by increases in training group scores but also by worsening in control group CHS (-2.00mph) and ball speed (-0.93mph). No group mean regressions were seen in any of the other testing scores. Given the age of both groups, it was an unexpected finding that CHS and ball speed values in the control group regressed over the 12-week period. Due to the intervention taking place in the off-season, it may be that these regressions occurred due to significant reductions in golf volumes by all players over the winter period. As such, these findings not only demonstrate improvements in CHS and ball speed because of the intervention but should also highlight the impact of the intervention in the prevention of CHS and BS regression over periods of reduced sports specific practice during the off-season. Therefore, emphasising the importance of resistance training interventions in off-season periods in youth golf, as well as potentially showing the deleterious effect of reduced golf practice volumes over this period (although this was not measured).

Several potential mechanisms could underpin the observed improvements in clubhead speed, ball speed, and changes in physical qualities. With many of the participants being post peak height velocity, increases in muscle cross sectional area through training are likely,[16, 156] and would result in increased force production.[91] This is supported by the observed increases in body mass within the training group. All of the structural changes during training will be supported by the increased testosterone, insulin like growth factor and human growth hormone the participants will have in adolescence compared to during childhood.[16] Underpinning neural mechanisms driving change over the training period include the improved motor unit recruitment, synchronisation and rate coding [164, 165] which will support improved power and strength characteristics.

A simultaneous limitation and strength of this study was the pragmatic nature of the exercise intervention. The specific exercise prescription was kept intentionally broad to allow for an individually tailored approach, where exercise progressions and regressions, as well as alterations in load and volume, were given based on individual need. This approach allows for a more realistic intervention which would be in-line with real-world resistance training support in youth golf. The recruitment and group allocation were a limitation of this study, with proximity/access to the training facility being a key determinant of group allocation. This is likely to have facilitated the high attendance rates achieved in the investigation but did not allow for randomisation of the groups.

Furthermore, while the intervention resulted in many positive changes in physical characteristics, the intervention was only one day per week, despite youth strength and conditioning guidelines recommending more frequent doses.[15-17] Despite this, the investigation was able to demonstrate changes in physical characteristics in-line with other previous interventions.[161] Future research would, therefore, benefit from comparing once per week doses to more frequent doses in youth golfers and youth athletes, in general, to understand if an increase in frequency would lead to a more substantial response. Despite the once per week dose being a limitation, it also represents a realistic training volume for many young athletes where time is likely to be split between a range of sports, academic, social and other commitments.[166] Recent research has highlighted a strong relationship between rotational and seated medicine ball throws and CHS,[157] but the present study did not measure medicine ball throws due to space limitations within the facility. Future research may wish to evaluate the effectiveness of interventions in eliciting changes in medicine ball throw ability in golfers, as well as specifically target medicine ball interventions which researchers have shown favourable outcomes for in sports requiring high rotational velocities.[154, 155] Finally, the inclusion of a maximal force production measure, such as the isometric mid-thigh for pull peak force, as used in previous work,[45] could be a valuable future measure to allow for improved quantification of maximal strength changes in youth golfers over the course of an intervention. However, a limitation of using this method of analysis may come through its subsequent practical application due to the likely limited access to force plates in youth golf training environments.

7.7 PRACTICAL APPLICATIONS

Strength and conditioning professionals working with youth golfers can use the findings from this study to inform the design and delivery of their programmes. The results from this work demonstrate a likely positive increase (3mph) in CHS and possible increases in ball speed (4mph) to threshold values in youth golfers training only once per week for 12-weeks. These improvements in CHS and ball speed are likely to lead to noticeable performance improvements on the golf course. The study was also able to demonstrate improvements in relevant physical characteristics in-line with previous work in youth athletes,[161] but from only one session per week. Therefore, supporting the use of a once per week training dose in youth athletes in general as well as youth golfers. This study also outlines a framework for programme design which is in-line with previous guidelines[15-17] and can, therefore, support strength and conditioning practitioners in their programme design for youth golfers.

8 CHAPTER EIGHT: EFFECTS OF A SIX-WEEK RESISTANCE TRAINING PROGRAMME IN YOUTH GOLF: A COMPARISON OF ISOMETRIC DOMINANT TRUNK AND CONCENTRIC DOMINANT MEDICINE BALL EXERCISES

8.1 CHAPTER OUTLINE

Having established the positive role resistance training can play on CHS, BS and physical performance in youth players, I seek to investigate further the optimisation of training based on the findings in Chapters Six and Seven. Within this chapter I also further the research in programme optimisation for golf, an area identified as lacking in Chapter Four. One of the key findings in Chapter Six is the strong relationship between rotational and horizontal medicine ball throws and clubhead speed. Therefore, this investigation compares explosive medicine ball exercises against static trunk training in an otherwise identical resistance training programme using a quasi-experimental crossover design. 15 male youth golfers take part in this experiment, I use clubhead speed, ball speed, as well as peak velocity for rotational and chest medicine ball, throws as dependent variables to evaluate the programme. While this study demonstrates pre/post improvements in golf CHS and BS measures, the study is unable to demonstrate improved outcomes for the medicine ball throw group.

This Chapter is organised as follows:

Section 8.2 introduces the underpinning rationale for designing a study which compares the addition of isometric dominant trunk or concentric dominant medicine ball training to a resistance programme on youth golfer CHS and BS.

Section 8.3 presents the methodological approach taken compare to the addition of isometric dominant trunk or concentric dominant medicine ball training to a resistance programme on youth golfer CHS and BS.

Section 8.4 highlights the results of the research which address the related research questions.

Section 8.5 onward offers discussion on the knowledge which I have created as a result of the study. I also propose areas for future development of the research in this field.

8.2 INTRODUCTION

Medicine ball training has been utilised throughout history, with recommendations for its use dating back to Galen (130-210AD), where he described its ability to 'provide health of the body, harmony of the part, and virtue in the soul'.[167] Given his documented involvement with Gladiators[168] and strength of opinion on the use of medicine ball exercise,[167] it is likely that these training methodologies have been involved in enhancing sports performance for over 1,800 years. However, in more recent times, a growing body of literature has emerged, often with mixed results. In some instances, medicine ball throws, used as a training intervention, have been shown to improve sports performance.[154, 169] However, these findings are not conclusive, with studies also demonstrating no difference between different training approaches,[170] or in some instances, a greater effect from standard resistance training.[171] These mixed findings not only make golf specific medicine ball research a worthwhile pursuit, but also highlight the difficulties of supporting the transfer of training to performance through more sport specific exercises.

The use of medicine ball throws, especially those predominantly in a transverse plane, will partly seek to mimic aspects of the golf swing in the hope of achieving a transfer of training into CHS and BS. Medicine ball training offers some relatively unique attributes which could support its use in golf. Many medicine ball throw exercises are high-velocity explosive movements, requiring the whole-body segmental summation of force, finishing with a release. Medicine ball exercises can also be conducted in a predominantly transverse plane if desired. These characteristics offer a considerable degree of similarity to those involved in the golf swing, and therefore offer a potential transfer to golf CHS and BS. The coach implementing medicine ball training could use a range of throw variants to increase the specificity of a given exercise towards a range of performance-related characteristics. For example, a rotational scoop toss will have a strong concentric rotational bias. Stepping into the throw will increase emphasis on force production through the lead leg. Catching and returning the ball will support force absorption and deceleration of the ball. A high to low throw with release into the floor can mimic the movement pattern of a golf swing more accurately. While many other variants are available, these examples highlight how the exercise options can offer versatility as well as the direction towards a range of golf specific needs. Regarding applications to the youth athlete, the versatility of the available exercises can also offer fun and enjoyment as well and prevent monotony.

The search for specificity and transfer to training outlined above is a complex one, and often not as achievable as it is logical. This is not only demonstrated by instances where the use of medicine ball throws have not led to more desirable outcomes than other forms of training but also through the ongoing debates, research and applied search for optimal training approaches. Researchers have documented that strength is likely to play an essential role in an athletes ability to express a variety of force-time characteristics.[172] As a result, an athletes ability to express themselves explosively may often be limited by their ability to produce high levels of force, which may support a general strength approach over interventions with higher perceived specificity in some instances. This may also mean that more specific and explosive exercises such as medicine ball throws may have less transfer to training if training age is lower and the athlete has a significant strength deficit.[172] As a result, it is not entirely clear whether the use of medicine ball training will offer benefits in youth golf populations, where training age may be low and is therefore worthy of further investigation.

Current golf literature appears to show an increasing interest in the specificity of golf training.[109, 112, 117] Having established impacts of resistance training in general,[40, 110, 115, 118, 121, 122] next logical steps in this field will include the search for methods and approaches which optimise training, this includes understanding the impact of specificity. Given the previously discussed potential mechanical similarities to golf, medicine ball training is therefore of interest. Golf research training interventions frequently use medicine ball exercises, but rarely compare them to other methods of training. This is despite the numerous studies which show strong relationships between medicine ball throws and golf performance in both adult[71, 76, 78] and youth[157] populations. Studies which have incorporated medicine ball variants into their training have often done so in conjunction with other training approaches.[40, 110, 112] This is appropriate and likely representative of how strength and conditioning professional might programme this exercise. Often medicine ball throws will be prescribed within a standard resistance training programme, sometimes at the start with other high skill or explosive exercises, in other instances, they might be prescribed at the end of a programme.[112] However, due to the lack of comparison against other training strategies, golf research to date does not offer an answer as to whether the use of medicine ball exercises within a training programme is warranted or shed light on its relative effectiveness.

Therefore, the purpose of this chapter was to investigate the effects of either an isometric trunk or concentric dominant medicine ball prescription within two otherwise identical once-weekly resistance training programmes over a six-week period. The medicine ball training was incorporated into a regular resistance programme and put against an isometric trunk training option. Young golfers are likely to have this type of training incorporated into their strength and conditioning programmes in this way; therefore, this approach had greater ecological validity.

8.2.1 Research Questions

My purpose within this chapter was to investigate Research Question 5 *'Does the addition of a concentric dominant medicine ball throw prescription lead to improved physical performance, CHS and BS outcomes when compared to isometric dominant trunk exercises in an otherwise identical resistance training programme delivered to youth golfers?'.* I will achieve this purpose by addressing the following Research Objectives:

- Successfully deliver the training interventions, as demonstrated through completion rates of no less than 85% and attendance rates for those completing at above 85% and through intention to treat analysis where appropriate.
- Demonstrate effectiveness of the intervention through statistical analysis of appropriate physical performance characteristics.

• Demonstrate the effectiveness of the intervention through statistical analysis of the golf CHS and BS measures.

8.2.2 Hypotheses

Relating to Research Question 5 and the associated Research Objectives, the hypotheses were:

- Between-group differences in rotational and chest medicine ball throw velocities would show meaningful improvements in favour of concentric dominant medicine ball training.
- Between-group differences in CHS and ball speed would show a meaningful improvement in favour of concentric dominant medicine ball training.

8.3 METHODS

8.3.1 Experimental approach to the problem

A quasi-experimental repeated measures crossover design with a two-week washout was used to ascertain the impact of, and the difference between two resistance training programmes on CHS, BS and physical characteristics in youth golfers. Two training groups performed a pre and post intervention field-based testing battery. During the six-week intervention, both groups continued their regular golf training while completing a once weekly intervention of resistance training in their respective intervention groups.

8.3.2 Participants

15 male golfers were recruited to take part in this study (age: 13.7±0.95 yrs., height: 169.4±5.3 cm, mass; 63.6±15.2 kg, HCP: 10.5±4.35 strokes). All golfers were competing at a

high level for their age group, as demonstrated through selection to an English county squad. Golfers mean maturity offset was 0.38 years as calculated using the Moore-2 maturity offset equation[158], previously discussed in chapter 7. The intervention took place over the off-season and players were injury free at the commencement of the study. Informed consent was gained from all golfers and their guardians before starting the investigation. The University Ethics Committee granted ethical approval. All participants were members of the same county golf union and were likely to have similar practice and competition schedules. Group allocation was concealed when determining participant eligibility.

8.3.3 Testing

All testing was completed for all golfers within a group in one day and within one session lasting one hour alongside a team of researchers. All researchers were assigned to a specific test to ensure high test-retest reliability. All researchers were trained on how to conduct their respective tests. Coaches were sent a document prior to the testing day, outlining all physical testing procedures and were asked to familiarise themselves with these prior to testing. On the day, around 30-40 minutes prior to testing, coaches were shown the testing procedures by the principle researcher, allocated to their individual testing station and then given the opportunity to practice with one another until they were happy with the process. In all tests, golfers completed three trials with a mean score taken for analysis. Body mass (kg) was measured before initial physical testing and calibrated the scales before use to ensure accurate measurement. Golfers self-reported their most up to date handicaps. Testing was completed on the first and last week of the six-week intervention for all golfers.

8.3.4 Clubhead speed and ball speed

An ES14 (Ernest Sports, USA) launch monitor was used to measure CHS and ball speed. The system was calibrated per manufacturer recommendations before testing. Golfers used their own driver, were blinded to all results throughout testing, and we used Titleist ProV1 golf balls for all shots. Shots were carried out on a golf matt and into a golf net on all occasions, to ensure a stable environment for testing. Golfers were permitted to complete a self-defined number of practice swings and hit balls until they felt ready to begin testing. Once ready, golfers were instructed to 'hit the ball as hard as you can'. Three driver shots were taken, with a 60-second rest between shots. Manufacturer reported accuracy for the ES14 Pro for clubhead speed and ball speed are ±4mph and ±2mph respectively. Separate to this study, test-retest reliability was evaluated using the methods described above over 2 separate testing sessions. Clubhead speed and ball speed were shown to be highly reliable between testing sessions (r=0.99) with minimal detectable change scores of 1.48mph for clubhead speed and 2.12mph for ball speed based on a 1.645 z-score, further details of the reliability study can be seen in Appendix A.

8.3.5 Rotational medicine ball throws

As a measure of rotational power, golfers were required to complete a rotational medicine ball throw into a wall. Using a 3kg medicine ball, the golfers were asked to adopt a golf stance and rotate and throw the ball as fast as possible into a wall 2-3m away. Feet were required to stay in touch with the floor, but the rear heel could lift and move like in a golf swing to achieve triple extension. If attempts did not meet these criteria, they were discarded and repeated. Three trials were taken with a 60-second recovery between each. Peak throwing velocity was measured using a PUSH Band 1.0 (PUSH Inc., Canada) attached to the golfers' trail arm as per manufacturer instructions for the exercise.

8.3.6 Chest medicine ball throws

The golfers were required to complete a double arm supine medicine ball chest throw. They were instructed to adopt a supine position, with their feet out in front of them. The golfer was then required to hold onto a 3kg medicine ball and throw it as fast and high as possible into the air. Three trials were recorded with a 60-second recovery between each. Peak throwing velocity was measured using a PUSH Band 1.0 (PUSH Inc., Canada) attached to the golfer's dominant arm as per manufacturer instructions for the exercise.

8.3.7 Training interventions

Both groups of golfers completed a one-hour resistance training session once per week. This training dose was selected following a survey of parents and players to ascertain a realistic and longer-term sustainable commitment to the programme and to ensure maximal compliance.

The training programme outline is shown in table 8.0. Training sessions consisted of approximately ten minutes of dynamic warm-up, 40 minutes of resistance training and ten minutes of specific trunk training as defined by their group allocation. We took a pragmatic approach to the resistance training intervention, using expert coaching from a qualified professional to meet the needs of the group. While we tailored the approach to individual and group needs using expert strength and conditioning support, the training sessions were designed with youth resistance training guidelines in mind.[15-17]

In addition to following the training session within table 9.0, the groups completed different specific trunk training interventions over the last 10 minutes of each weekly session. The isometric trunk training group completed a series of two sets of side planks, front planks and three sets of loaded carries. Golfers completed side planks and front planks in one-minute blocks with minimal rest, and three sets of loaded carries over 20m with an appropriate load for the golfer based on expert coach judgement. The concentric dominant, explosive trunk training group completed three sets of three to six left, and right-sided rotational medicine ball throws into a wall and three sets of three to six slam balls with 30-60 second rest periods using an appropriate load for the participant based on expert coach judgement.

Table 8.0: Resistance training programme outline

Phase	Method (progression based on technical competency and capacity)	Description	Sets/Reps/ Rest (mins)	Typical coached lifts/exercises (modified to individual need, no more than 5-6 exercises per session)
1	Introduction to resistance training	Introduction to basic exercises and movement patterns	1-2/8-12/<1	Squat, press-up, modified pull-up, hinge, plank/other trunk
2	Bodyweight and soft resistance training	Development of movement patterns into structured exercise. Adding soft resistance (bands, dumbbells, kettlebells, suspension trainers)	2-4/6-12/<1	Goblet squat, press-up, modified pull-up, kettlebell (KB) Romanian deadlift (RDL), plank/KB loaded carries
3	Introduction to barbell training	Continuation of bodyweight work, but with an introduction of barbell lifts and technical coaching with low-moderate resistance	3-6/5-8/2-3	Barbell (BB) back/front squat, BB overhead press, BB bench press, BB row, BB/hex bar deadlift/RDL, KB loaded carries, medicine ball throws
4	Barbell progressions	Building on barbell lifts by applying additional load and working at moderate-higher resistance with technical mastery.	2-5/2-5/2-5	Barbell (BB) back/front squat/jump squat, BB overhead press, BB bench press, BB row, BB/hex bar deadlift/RDL, hex bar jumps, KB loaded carries, medicine ball throws

8.3.8 Statistical analysis

The data were reported as mean±SD. Intraclass correlation coefficients for all dependent variables were reported, as shown in table 8.1. All outcomes have been expressed as the value with 90% confidence intervals. These values were given as both absolute data and standardised data. Standardised data were calculated using Cohens D effects sizes. Threshold values were carefully considered for each dependent variable to ensure practical impact. Ball speed was given the threshold value of 4mph and CHS the threshold of 3mph as this is the likely degree of change required to elicit a 10-yard increase in driving distance.[160] A 10-yard improvement would result in a golfer being able to select a different club and therefore have a more desirable option for their second shot, which was deemed as practically meaningful and confirmed through discussions with national coaches. These CHS and ball speed thresholds also sat within the test-retest reliability values previously reported. Threshold values were set for chest, and rotational medicine ball throws at minimal detectable change values(MDC). MDC values were calculated for chest and rotational medicine ball throws using methods described by Haley & Fragala-Pinkham[173] based on the reported ICC values and at 90% confidence intervals. These resulted in thresholds 0.35m.s for chest medicine ball throws, 0.53m.s for left-sided rotational medicine ball throws, and 0.60 for right-sided rotational medicine ball throws.

Magnitude-based inferences were determined using methods previously described.[162, 163] All inferences were based on the thresholds above. The chance of the difference being positive, trivial or negative and allocation of subjective descriptors were based on the following scale: 1%, almost certainly not; 1–5%, very unlikely; 5–25%, unlikely; 25–75%, possible; 75–95%, likely; 95–99%, very likely; and 99%, almost certainly. The magnitude of effects were classified mechanistically, where if the 90% confidence limit crossed thresholds of the smallest positive and negative effects, the effect was ‘unclear’.[163]

8.4 RESULTS

Key descriptive statistics and mean changes are shown in table 8.2. Pooled data demonstrated improvements in clubhead speed (1.73±4.53 mph) and ball speed (3.50±6.61 mph) from both interventions. Magnitude-based inferences using the previously determined thresholds showed no practically meaningful between-group differences (see table 8.3).

Each training group achieved 95% attendance, with each player missing an average of 0.31 sessions of the six available. All players completed the resistance training programme and attended pre and post-intervention testing.

Table 8.1: Intraclass correlation coefficients for dependent variables

Test	ICC
CHS	r=0.98
Ball speed	r=0.97
Chest medicine ball throw	r=0.86
Rotational medicine ball throw (left)	r=0.89
Rotational medicine ball throw (right)	r=0.91

Table 8.2: Effects of the six-week interventions on CHS, ball speed and physical characteristics (descriptive changes in group results)

Variable	Concentric trunk baseline	Static trunk baseline	Concentric trunk post	Static trunk post
CHS (mph)	92.69±7.85	94.69±7.98	94.71±7.31	96.36±8.26
Ball speed (mph)	130.67±9.85	133±11.69	134.36±10.63	136.83±10.72
Chest medicine ball throw (m.s)	1.59±0.31	1.72±0.22	1.70±0.18	1.65±0.22
Rotational medicine ball throw (L) (m.s)	3.85±0.55	3.62±0.38	3.64±0.37	3.84±0.59
Rotational medicine ball throw (R) (m.s)	3.50±0.76	3.49±0.38	3.53±0.35	3.69±0.55

Table 8.3: Effects of six-week medicine ball intervention against isometric trunk intervention on CHS, ball speed and physical characteristics (confidence intervals and magnitude-based inferences, standardised using effect sizes)

Variable	Concentric trunk baseline	Static trunk baseline	Minimum important change thresholds (standardised value)	Δ Difference (90% CI)	Standardized Δ Difference (90% CI)	Chances of effect better/trivial/worse (based on thresholds)	Qualitative Assessment (Based on MIC)
CHS (mph)	93.2±8.02	94.69±7.98	3(0.67)	0.37(-2.54 to 3.25)	0.08(-0.56 to 0.72)	7/90/3	Likely trivial
Ball speed (mph)	129.80±9.43	133±11.69	4(0.61)	-0.14(-4.51 to 4.22)	-0.02(-0.69 to 0.65)	6/87/7	Unclear
Chest medicine ball throw (m.s)	1.50±0.14	1.72±0.22	0.35(1.16)	0.18(-0.29 to 0.38)	0.59(-0.96 to 1.26)	8/92/0	Likely trivial
Rotational medicine ball throw (L) (m.s)	3.66±0.48	3.62±0.38	0.53(0.77)	-0.44(-0.82 to -0.62)	-0.64(-1.18 to -0.90)	0/66/34	Possibly trivial
Rotational medicine ball throw (R) (m.s)	3.23±0.87	3.49±0.38	0.60(0.97)	-0.18(-0.59 to 0.23)	-0.29(-0.95 to 0.37)	0/95/5	Very likely trivial

8.5 DISCUSSION

The purpose of this study was to compare the effects of an isometric trunk against concentric dominant medicine ball prescription within two otherwise identical once-weekly resistance training programmes over a six-week period. This was achieved through evaluating changes in CHS, ball speed, and medicine ball rotational and chest throw velocity. The results from this study demonstrate pooled improvements in CHS which were similar to the findings in Chapter Seven and other research. However, between-group analysis revealed no meaningful differences in CHS(CI90 -2.54 to 3.25mph), ball speed(CI90 -4.51 to 4.22mph), rotational medicine ball throw to the left(CI90 -0.82 to -0.62m.s) or right(CI90 -0.59 to 0.23m.s), or medicine ball chest throw(CI90 -0.29 to 0.38m.s). These results indicate that while training youth golfers is likely to be effective, as shown in Chapter Eight, the specific use of medicine ball throws over static trunk work is unlikely to offer additional training benefit. The approach to this research was in line with the pragmatic research philosophy outlined in the thesis introductions. Many of the same pragmatic decisions were made in study design, as outlined in Chapter 7. In addition to these, medicine ball throws and static trunk work were integrated into a broader programme, as opposed to being investigated in isolation. This was to increase the applicability of the results, as individual exercises would always be given to athletes as one component of a wider programme in practice. Therefore, this programming approach was seen as more context specific. The study took place over only 6-weeks, with the repeated measures approach this involved 12-week of exercise intervention. Therefore, the total study length remained approximately equal to that of Chapter 7 to ensure high retention and compliance rates over the already successful 12-week time period.

While the findings from the study demonstrated no additional benefit from the use of medicine ball throws over static trunk work, they also showed no detriment in CHS or BS or training adaptation from their use. Given the wide variety of trunk exercises on offer through medicine ball throws as well as the enjoyment they can offer youth programmes, their use should not be actively discouraged as a result of this investigation. From the results of this study, we can look upon them as an equal alternative to other trunk training within a resistance training programme for golfers, rather than a superior option. The overall improvements seen in CHS, BS and physical qualities within groups could be in part due to improvements in muscle cross sectional area and intramuscular neural adaptations discussed in Chapter 7.[16, 91, 165 164] However, the lack of additional between group differences from medicine ball training could be present for multiple reasons. The lack of training experience within the groups investigated may be of particular note. Given the training ages of the youth players in this study did not exceed six months, they may have a positive reaction to most training interventions, given their relative condition.

Moreover, research has previously established the importance of strength in supporting explosive strength qualities.[172] With a low training age, it is likely that the general resistance training will have addressed a strength deficit in both interventions for the study cohort, and more specific solutions were not required.[172, 174, 175] However, it is also notable that low training ages are likely to be common within youth golf populations, and therefore these results will be generalisable to many youth golf populations. Therefore, the findings from this investigation are useful in demonstrating the potential need for general resistance training over exercise specificity in youth golfers with relatively low training ages. However, further research would benefit from exploring the role of increased training specificity as training age and strength level increase in youth golfers.

Similar to that of the previous chapter, a simultaneous limitation and strength of this study was the pragmatic nature of its intervention. In this regard, direct comparisons of the medicine ball throw against the isometric trunk work were not made, but instead, they were compared against one another within the context of a more general resistance training programme. Moreover, the loads and volumes of the resistance training programme were given based on individual need against a previously outlined approach. While this does reduce control of extraneous variables it also offers a high degree of ecological validity. When working with a youth golfer, or youth athlete of any kind, coaches would not reduce training programmes to one exercise. They would create and deliver multi-faceted programmes which incorporated a range of resistance-based exercises. A coach would adapt these exercises to the needs of the individual athlete and volumes and loads would be altered in line with established guidelines,[15-17] alongside expert coach knowledge. Therefore, the decision to reduce control of the other programme variables was a conscious one and allows to a fair and ecologically valid comparison between two different trunk training approaches. For a medicine ball intervention or any other intervention, to offer a superior training effect, it would have to be demonstrated that an increased training effect occurs within the context of a 'real world' training environment and programme. A possible further limitation of the study was its duration, at only six weeks. However, previous investigations have been able to distinguish between training approaches over this timeframe.[176] It could be argued that given more time, one training intervention may have separated itself from the other. Having said this, the data did not indicate any particular trend towards one intervention over the other at 6-weeks, and therefore this may not be the case. Also, these points, an optimal training dose in youth athletes,[19] and certainly in youth golfers, is not clear. Therefore, we may require frequencies higher than once weekly to distinguish between training approaches.

A range of further investigations is possible in this field, given the relative infancy of youth golf training research. However, based on the observations made within this study, and in conjunction with the discussion, the author would recommend investigations into the effects of medicine ball training on youth golfers with a higher training age, and for a longer duration. Also, physical profiling strategies could be used to identify strength or explosive strength deficits in youth golfers. This information could then inform and more appropriately target strength or explosive strength interventions for players. A more systematic approach such as this may help to improve optimisation of resistance training in youth golfers. Finally, optimal training frequency in this population is not yet known, and research across sports does not offer clarity in this area.[19] Therefore, interventional studies comparing different weekly training frequencies could help improve understanding of what training dose may be optimal in this population.

8.6 PRACTICAL APPLICATIONS

The results of this study indicate that a once-weekly resistance training programme may elicit increases in clubhead speed and ball speed over a six-week period in youth golfers. However, meaningful between-group differences were not observed in clubhead speed, ball speed or medicine ball throw velocity when comparing the additional use of concentric explosive medicine ball or isometric trunk strength work. This study highlights the potential benefits of resistance training for youth golfers but is unable to distinguish between different approaches to trunk work within sessions for maximising driving distance or associated physical qualities. Therefore, strength and conditioning coaches may wish to employ medicine ball exercises has part of a holistic approach to training, however, should not expect a superior training effect compared to other forms of trunk training.

PART FIVE: CONCLUSIONS

"The road to success is always under construction"

Arnold Palmer

9 CHAPTER NINE: CONCLUSIONS AND SUMMARY

9.1 INTRODUCTION

Within the thesis statement in Chapter One, I put forward two conjectures which established my work:

1) All youth golfers should complete a warm-up to support their performance goals. Warm-ups can be completed in a short period, using no additional equipment and can improve clubhead speed and driving distance as well as shot quality, which will lead to higher levels of performance.

2) All youth golfers should engage in resistance training, coached by an appropriately qualified professional, in order to support their performance goals. Resistance training only needs to be completed once weekly and will enhance desirable physical qualities, as well as improve clubhead speed, which will lead to higher levels of performance.

In order to test these conjectures, the purpose of this thesis was to (i) assimilate the background golf strength and conditioning literature, (ii) establish the impact of warm-up on youth golf CHS and perceived shot quality, (iii) identify physical characteristics which relate to youth golf CHS, (vi) establish the impact of resistance training on youth golf CHS and BS. Within this chapter, I assess the outcome of these through the research questions. I also discuss the limitations of this thesis and directions for future research in this field.

9.2 RESEARCH QUESTION 1

What is the scope of literature exploring physical preparation of the golfer in areas of warm-up, physical characteristics associated with golf performance and the use of strength and conditioning interventions to enhance performance?

In order to adequately address Research Question 1, I broke it into three sub-questions:

I. *What is the scope of literature investigating the impacts of warm-up on golf performance?*

It is likely that completing a physical warm-up will improve golf performance in adult players. As well as increased in CHS and distance, performance improvement could come by way of improved shot quality through enhanced ball strike and swing kinematics. It is likely that static stretching will have deleterious impacts on CHS, distance variables and shot quality, and that these effects may last for at least 1 hour after warm-up. However, there is a sparsity of research into youth golf populations, so I highlighted the need for further research in this area.

II. *What is the scope of literature investigating the relationships between physical characteristics of golfers and golf performance?*

There are an array of positive relationships between specific physical qualities and golf performance, highlighting the potential importance of physicality within the game. Most notably, higher body mass, greater limb girths, increased whole, upper and lower body strength and explosive strength are consistently shown to have strong relationships to golf performance in adult golfers. While these relationships do not mean the physical qualities are causative of the performances, they do indicate possible dependent variables for future interventional research. Also, performance related physical qualities identified across the discussed literature have potential to inform programme design and areas of focus for the interventions given within future research. However, there is a sparsity of research into youth golf populations, so I highlighted the need for further research in this area.

III. *What is the scope of literature investigating the impacts of strength and conditioning on performance?*

The current research demonstrates the positive impact strength and conditioning work has on golf performance in adult players. Most likely impacts of training are increases in CHS and distance. However, researchers have also shown improvements in other, more skill related tasks within the sport. High load and explosive exercises were the most effective training methods when compared to lower load training. There is a lack of high-quality work investigating the impact of training interventions on youth golfers as well as those investigating optimal training methods through comparison of different training methodologies, so I highlighted the need for further research in this area.

9.3 Research Question 2

Are clubhead speed and shot quality enhanced though an appropriately designed warm-up in high-level youth golfers?

Yes. As with adult golfers, youth golfers respond positively to a warm-up. A combined dynamic physical warm-up and club warm-up improves clubhead speed and self-reported shot quality in youth golfers. However, a club warm-up alone does not seem to be sufficient in eliciting these same improvements. Therefore, youth golfers should be encouraged to warm-up before practice and competition, and this warm-up should include dynamic exercises as well as golf shots. Warm-ups can be completed in a short period, using no additional equipment and are therefore highly accessible to youth golfers.

9.4 RESEARCH QUESTION 3

What physical performance measures are most strongly related to clubhead speed in youth golfers?

The strongest positive relationships of those tested exist between CHS and body mass, countermovement jump predicted power, seated and rotational medicine ball throw distance. While subtle differences were present between males and females, these concentric dominant power exercises were consistently shown to be of significance. Interestingly, countermovement jump height was shown to have one of the least significant relationships with clubhead speed, which is likely to be because golfers are not required to displace their mass and therefore absolute is more important than relative power. As a result, we should exercise care selecting the right countermovement jump test for golfers. These findings indicate that resistance training interventions may be more effective if they support increases in explosive exercises like those outlined above.

9.5 RESEARCH QUESTION 4

Does resistance training, focused on developing strength and explosive strength, result in greater physical performance, CHS and BS outcomes than no training in youth golfers?

Yes. Implementing a once-weekly supervised resistance training programme based around fundamental compound lifts and explosive exercises increased clubhead speed and ball speed as well as desirable physical characteristics in youth golfers. The resistance training programme also appeared to protect against CHS degradation over the off-season. The differences observed in the training group had meaningful on-course transfer, by improving CHS enough to gain an additional 10-yards on driving distance, which would equate to a positive change club selection on the second shot. Therefore, youth golfers should participate in resistance training on a weekly basis to improve their CHS and BS. Training only once per week is enough to elicit desirable responses, which is a realistic time commitment for an aspiring youth golfer.

9.6 Research Question 5

Does the addition of a concentric dominant medicine ball throw prescription lead to improved physical performance, CHS and BS outcomes when compared to isometric dominant trunk exercises in an otherwise identical resistance training programme delivered to youth golfers?

No. When comparing two otherwise identical resistance training programmes, the use of concentric dominant medicine ball or isometric dominant trunk exercises made no difference to the outcome of desirable physical performance, CHS or BS measures. However, we saw improvements in CHS and BS in both interventions. Therefore, when dealing with youth golfers who are likely to have a relatively low training age, focus towards specific explosive golf exercises may not be as important. Instead, engagement in a general resistance training programme focused on increasing strength and explosive strength is effective. We may wish to use medicine ball exercises or static trunk exercises within training programmes, and both are likely to be useful, but one no more than the other. As a result, coaches may wish to interchange these exercises to add variety and fun into the programme rather than focus on their sports specificity.

9.7 LIMITATIONS

I have identified some limitations within the research contained within my thesis. Many of these limitations are areas which researchers could address in future work:

- After a self-evaluation process using PEDro, the warm-up intervention scores a 7/10 and both resistance training interventions score a 6/10. Whilst this shows that the studies were of high quality, all three studies lost points in some key places. Loss of points were consistently due a lack of participant, coach and assessor blinding. Difficulties with blinding are common in the field of research within the thesis, as demonstrated during the literature reviews, and this is especially true when undergoing self-directed research within a PhD. Participant blinding is often likely to be impractical, because designing sham warm-ups and training interventions are not likely to be possible. Despite this, blinding of coaches and assessors is more likely to be achievable. Therefore, future research should consider feasibility of blinding in the design stage and implement it where possible. Further loss of points came through recruitment challenges, often resulting in a lack of randomisation of participants to intervention and control groups. This was a similar limitation amongst the majority of studies reviewed from the previous literature. Whilst a challenge, future research should aim to build on this where able, and consideration should be given to the feasibility of this when designing studies.

- The warm-up study failed to measure shot-quality directly, through measures of accuracy, dispersion, centeredness of strike etc. Therefore, the actual impact on the golfers shot as a result of warm-up is not known.

- There was not an exercise based dynamic warm-up only group within the warm-up study. This make it difficult to know the impact of this component in isolation. However, on the other hand, it is unlikely that a golfer would go on to practice or perform without hitting shots, and therefore this wasn’t deemed necessary.

- Due to challenges with recruitment, the warm-up and physical characteristics studies took place in multiple locations, with testing taking place outdoors. Therefore, performance variables were not controlled as well as if they had been measured in a laboratory.

- There was an unforeseen reduction in control group clubhead speed in the 12-week study, this may be due to reductions in golf practice during the off-season. Speculatively the resistance training may have reduced this impact given the positive result in the intervention group. However, golf practice volumes were not measured or controlled for, and therefore this cannot be known.

- Measures of strength were not used in the physical characteristics study and resistance training intervention studies. Given the effectiveness of the general strength programme and the lack of additional impact of the medicine ball throw intervention, increases in strength may be a key driver for performance gains in this group. Measures such as isometric mid-thigh pull, which have been used with adult golfers, are low skill, and have been used within youth literature may be of use in future work.

- An optimal dose of resistance training was not established. Both intervention studies in this area only compared a once-weekly programme to no training. Therefore, it is not possible to give recommendations on the frequency youth golfers should be training, only that once-weekly training is effective.

- The youth populations tested throughout the research had a low training history, therefore the results may not be generalisable to youth golfers who have been training for longer periods of time.
- A pragmatic approach to the studies was consciously taken to increase ecological validity. However, in doing so there is a reduction in the control of variables making the results more susceptible to extraneous variables.

9.8 FUTURE DIRECTIONS

During this thesis, I have identified a wide range of areas for further research. However, a few critical areas of research are of high priority and could act as logical next steps from this work. Firstly, a more thorough assessment of the implications of warm-up and resistance training for shot quality would be of great interest. While this could be in the form of simple measures such as accuracy to a target, ball dispersion or centeredness of strike, more specific biomechanical measures would add great insight. If there are increases in CHS, driving distance and shot quality, then changes to the kinematics and or kinetics of the golf swing must be occurring. More thoroughly understanding this will be of great value for enhancing the impact of resistance training or warm-up interventions.

Optimisation of warm-up approaches would also be of great value. The research in adult populations combined with the study conducted within this thesis offers a great deal of possible warm-up approaches. A better understanding of an optimal warm-up for performance enhancement would be of great benefit.

Regarding physical characteristics and resistance training intervention studies, the use of robust strength measures as a variable would add greatly to the current knowledge. Given the responses to resistance training interventions, it may be that strength is a crucial driver for increases in CHS, especially in youth golfers with a low training age. As such, the use of measures such as an isometric mid-thigh pull for peak force, or similar low skill maximal force variables could bring additional insight into this area.

An area which I began in Chapter Eight, but still has significant room for growth, is that of optimisation of resistance training. A continued comparison of different approaches to training would help refine the approaches a strength and conditioning coach may take with a golfer. Moreover, the 12 and six-week interventions both involved only once-weekly training. As a result, understanding the impact of training frequency could be an important area for further investigations. I chose a once-weekly training intervention because it was able to fit most effectively with the young golfers' schedules. However, for those with more time, it is essential to be able to advise what an optimal frequency of training is. Should a strength and conditioning coach be recommended only once weekly, or should it be more?

In this thesis, I researched the impacts of resistance training on young golfers with a low training age. As such, it may be that youth golfers with more resistance training experience may respond differently or require a more specific approach to their training. As such, training studies comparing approaches amongst a more experienced resistance training group of young golfers may be of benefit. However, given the current landscape, these populations may be quite rare, making the studies challenging to complete and also resulting in low levels of generalisability.

Finally, while resistance training and warm-up practices in youth populations are improving, they are still sub-optimal. Many myths and misconceptions about the impact and appropriateness these interventions still exist amongst fitness professionals, players, coaches, parents and medical staff. Also, young golfers do not always action good advice as well as they could. Research investigating the impacts of an optimal approach to resistance training and warm-up is essential. However, they are of no use if the individual athletes and their support teams do not implement this advice. Therefore, research investigating methods to influence positive behaviour change and adherence in this population could be of great importance. Especially when considering positive behaviours instilled within this group will likely lead to improved behaviours in adulthood, allowing for greater long-term effectiveness of strength and conditioning support.

9.9 CONCLUSIONS

Within this thesis, I provide a wide range of information which supports the conjectures posed at its inception.

Having identified research supporting the impacts of warm-up on adult golfers, it became apparent that there would be a likely positive transfer of these principles to youth golfers. However, no research existed which had investigated, let alone demonstrated, this to be the case. Through this thesis, it became clear that youth golfers' CHS and perceived shot quality were also able to benefit from an exercise-based warm-up. The thesis was also able to show the ease at which these improvements could be enjoyed, having presented a simple and time efficient warm-up requiring no additional equipment.

After presenting literature which established the potential importance of a range of physical characteristics through relationships with golf performance it became evident that this was not the case in youth golf populations, where there was a dearth of research. Moreover, while researchers have established resistance training as useful for performance enhancement across a range of adult golfers, the research on youth golfers lacked again. Following the identification of this knowledge gap, this thesis has been able to show that a range of physical characteristics, mostly related to explosive strength characteristics, have strong relationships with youth golf CHS. Also, the thesis has shown how the implementation of a simple once weekly resistance training intervention can improve desirable physical characteristics as well as CHS and BS in youth golf populations. Also, that adding complexity through targeted golf specific work may not be as important as building a programme which approaches fundamental compound strength and explosive strength exercises.

Within this thesis, I offer support to strength and conditioning coaches, players, parents, golf coaches, national governing bodies and other involved parties. I have demonstrated the importance of good warm-up and resistance training practices for youth golfers wishing to improve their CHS, BS and perceived shot quality. Not only that, but I offer practical, applied and realistic approaches which I have already implemented in real-world environments nationwide.

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