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**Approach-Iron Play in High Performance Golf:
From Testing to Tournament Play**

This thesis is presented for the degree of
Doctor of Philosophy

Samuel John Robertson

Edith Cowan University
School of Exercise and Health Sciences
Faculty of Health, Engineering and Science

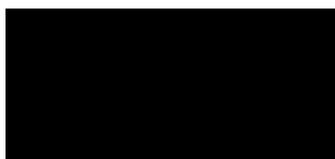
2013

DECLARATION

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ACKNOWLEDGEMENTS

A number of important people have been involved in both developing and supporting the undertaking and completion of this thesis.

To Associate Professor Angus Burnett, your guidance, wide-ranging expertise and incredible work ethic were invaluable in ensuring this project has been both an enjoyable and successful experience.

To Mr Brad James and Mr Matt Cutler at Golf Australia, your continued support and willingness to innovate for the betterment of Australian golf has been essential in enabling the completion of this project.

To Dr Tapan Rai, your statistical support, particularly in the early days of development was much appreciated.

To Mum & Dad, without your support (both in-kind and financial!) throughout the duration of this project (as well as my preceding studies) its completion would not have been possible.

To Adriana, your patience and understanding throughout the undertaking of this work has been fantastic. I look forward to an increase in nights spent away from the work desk, with both you and our new daughter, Emily.

ABSTRACT

The capability of a golfer to record a low score depends upon well-developed abilities in each of the recognised on-course skill components (driving the ball off the tee, hitting approach-iron shots, hitting short-iron shots and putting). Despite approach-iron play being considered perhaps the most important and definitely the most practiced skill in the game, the ability to quantify the golfer's ability to hit approach-iron shots in a controlled, off-course environment (eg. training) cannot yet be undertaken due to the lack of appropriate assessments. Such tools have considerable potential for use in both the field and in research for implementation in intervention studies, monitoring of athlete improvements over time as well as for use in talent identification programs. In this doctoral thesis which consisted of five studies, two testing instruments (Nine-Ball Skills Test and the Approach-Iron Skill Test) were developed to assess approach-iron ability, and their measurement properties (eg. reliability, validity) were determined.

In the first study of this thesis, the Nine-Ball Skills Test was developed to assess the ability of golfers to shape and control the golf ball whilst attempting to maximise accuracy. In this study, golfers (elite, $n = 14$; high-level amateur, $n = 16$) hit a series of nine shots with a 5-iron with differing combinations of trajectory (straight, fade, draw) and height (normal, high, low) at a predetermined target area. The scoring system in this test predominantly relied upon the accuracy of each of these shots via a commonly used performance indicator called the percent error index (PEI). This is a measure which is based around the resultant distance the ball lands from the hole of which its components are determined by a real time Doppler radar launch monitor.

In the second study, the Approach-Iron Skill Test was developed as a second measure of approach-iron ability in high performance golfers. The test differed from the protocol used in the first study in that players (elite, $n = 26$; high-level amateur, $n = 23$)

were requested to hit a series of three straight shots using a club of their choice to a target placed at nine different distances (55, 65, 75, 85, 95, 105, 125, 145, 165 m). Each shot in this test was scored using the same PEI method as used in Study 1. For a test to be truly useful in the practical arena there needs to be evidence of its reliability and validity. Both the Nine-Ball Skills Test (Study 1) and the Approach-Iron Skill Test (Study 2) showed fair to good test re-test reliability respectively. Additionally, both tests were assessed for content validity and showed a very good level of construct validity (discriminative) between elite and high-level amateur players.

In the third study, the ability of high-level amateur players to estimate the distances of approach-iron shots was investigated. This ability is important for high-level and elite players for the purposes of performance analysis and longitudinal collection of on-course, competition-based data. The main aim of this study was to assess the accuracy and precision of distance measurements made for approach-iron shots by high-level players in actual on-course play. Four measurements (Distance to Hole, Approach Shot Distance, Ball to Hole Distance and PEI) were assessed for their agreement with known distances obtained from a laser rangefinder and/or steel retractable tape measure during actual tournament play. All four measures investigated in the study showed a good level of agreement with known distances and reported low root mean square errors of prediction.

In the fourth study, a systematic review of development and assessment methods of sporting skill outcome tests was undertaken. The objective of this study was to systematically review methodological quality, measurement properties (reliability, validity, responsiveness) as well as the feasibility of skill outcome tests. From analysis of the 22 studies that were selected after meeting the inclusion and exclusion criteria, it was found that the majority of studies were of adequate methodological quality. Further,

whilst the studies adequately investigated test-retest reliability as well as content and construct validity, criterion-related validity (in particular, predictive validity) was not investigated in the majority of the assessments. Further, responsiveness was not investigated in the majority of studies and the reporting of feasibility considerations was minimal. A framework for sporting skill test design based on the findings of the review as well as existing measurement theory literature was also recommended for the benefit of future studies.

In the final study of the thesis, the convergent and predictive validity of both the Nine-Ball Skills Test and the Approach-Iron Skill Test was investigated. A group of high-level amateur golfers ($n = 24$) initially undertook both tests during the space of one week. Following this, data relating to their approach-iron performance in tournament scenarios (most notably, PEI) was collected over a 90-day period. A moderate correlation was noted between scores for both skills tests. Further, using generalised estimating equations (controlling for both the lie of the ball and shot distance) it was shown that both the Approach-Iron Skill Test and the Nine-Ball Skills Test were significant predictors of on-course approach-iron performance. The Approach-Iron Skill Test showed a strong ability to predict on course approach-iron performance.

The original and innovative studies within this thesis certainly have practical significance for golfers and coaches near, and inclusive of, the elite end of golf. The development of golf skill tests displaying good measurement properties help to provide useful tools for use by researchers, coaches and players to assess ability in approach-iron play. Future study should focus on developing similar protocols for the remaining components of performance to golf, using the development methods and measurement characteristics examined in this thesis as a template for design.

LIST OF PUBLICATIONS AND SUBMISSIONS

Publications in Peer-Reviewed Journals where Candidate was First Author

Robertson SJ, Burnett AF, Newton RU, Knight PW. Development of the nine-ball skills test to discriminate elite and high-level amateur golfers. *Journal of Sports Sciences* 2012; 30: 431-437.

Robertson SJ, Burnett AF, Newton RU. Development and validation of the Approach-Iron Skills Test for use in golf, In-Press, *European Journal of Sports Science* 2013; DOI: 10.1080/17461391.2012.757809.

Robertson SJ, Burnett AF. Accuracy of high-level player-reported measurement of approach-iron shot distances and accuracy in golf. *International Journal of Sports Science and Coaching* 2013; 8 (4): In-Press.

Robertson SJ, Burnett AF, Cochrane J. Tests examining skill outcomes in sport: A systematic review of measurement properties and feasibility. *Sports Medicine*; Accepted.

Robertson SJ, Burnett, AF. Two tests of approach iron skill and their ability to predict tournament performance in high-level golfers. *Journal of Sports Sciences*; In-Second Review

Conference Presentations where Candidate was First Author

Robertson, S.J. & Burnett, A.F. An examination of swing and launch kinematics of golf approach-iron shots hit with varying height and trajectory. 30th Conference of the International Society of Biomechanics in Sports, Melbourne, Australia, July 2012, (Oral Presentation).

Robertson, S.J. The relationships between skill testing and on-course tournament performance in golf. Asia Pacific Professional Golfers' Association Summit, September 2012, (Oral Presentation.)

LIST OF ABBREVIATIONS

3D	Three dimensional
CV	Coefficient of variation
GIR	Greens in regulation
GPS	Global positioning satellite
ICC	Intra-class correlation coefficient
LOA	Limits of agreement
MCID	Minimum clinically important difference
MSEP	Mean square error of prediction
PEI	Percent error index
PGA	Professional Golfers' Association
RE	Residual error
RMSEP	Root mean square error of prediction
SEM	Standard error of measurement
TEM	Typical error of measurement
US	United States

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CHAPTER 1 – Introduction

An overview of the literature relevant to this thesis has been presented in four sections below (sections 1.1 to 1.4). The first discusses the extensive history of performance assessment in golf and examines the various measures used to determine the overall ability of a player. In the second section, the four main components of performance in golf (driving, iron play, short game and putting) are examined and clearly defined. The third section discusses a brief history of the methods and technology currently utilised in the sport in which to quantify performance indicators, in particular those mentioned in previous sections. Section four discusses the considerations particularly relevant to both the development and utilisation of skill assessments in sport. Specifically, the ability of such tests to predict performance in real or competitive scenarios is discussed. The specific objectives of each of the studies contained within the thesis have been detailed in Section 1.5, with the limitations and delimitations stated in Section 1.6. Finally, a statement regarding the significance of the overall thesis has been provided in Section 1.7.

1.1 Overview of Performance Measurement in Golf

The sport of golf dates back to the 15th century and today has over 32,000 participants worldwide (Fradkin *et al.*, 2004) The primary aim of the game is to achieve a score as low as possible and can be played in either an individual or team format. Multiple full-time professional tours also now exist across the United States, Europe and Asia, further enhancing interest in the sport from both social and more serious participants. Despite being considered largely a skill-based sport, it is well established that a combination of physical, psychological, technical and strategy-related factors (Farrally *et al.*, 2003 Doan *et al.*, 2006; Hellstrom, 2009).

Traditionally, investigations into an individual golfer's level of performance have been undertaken through the recording of actual player outcomes. For example, measures such as average score (Belkin *et al.*, 1994; Finley & Halsey, 2004; Doan *et al.*, 2006) total earnings (in \$) (Nix & Koslow, 1991; Larkey, 1994; Dorsel & Rotunda, 2001; Hellstrom, 2009) and world ranking (Davidson & Templin, 1986; Larkey, 1994; Jones, 1998) have all been used by golf analysts and researchers. Although these outcome measures are considered useful information on which to assess the standing of a player within the golfing community, they do not provide information relating to the four generally accepted on-course skill components, they being; driving, iron play, short iron play and putting. By collating detailed information regarding each of these components, a player's relative strengths and weaknesses can be better assessed and relative contributions towards performance may be better ascertained. The main objective of this thesis therefore, was to specifically examine approach-iron play in high-level amateur golfers.

In sporting scenarios, a performance indicator (PI) has been referred to as an "action variable that aims to define some or all aspects of a performance." (Hughes & Bartlett, 2002, p. 739). Examples of PI's related to the four on-course skill components

in golf (Hellstrom, 2009) are shown in Figure 1.1. However, despite some investigations into the relationships between on-course PI's and playing performance having been undertaken previously, (Farrally *et al.*, 2003; James, 2007; Broadie, 2008) there is still conjecture as to each of their relative importance. This may be due to a lack of standardised definitions for each of these skills, unsubstantiated links with performance outcomes, as well as the fluidity of the professional game.

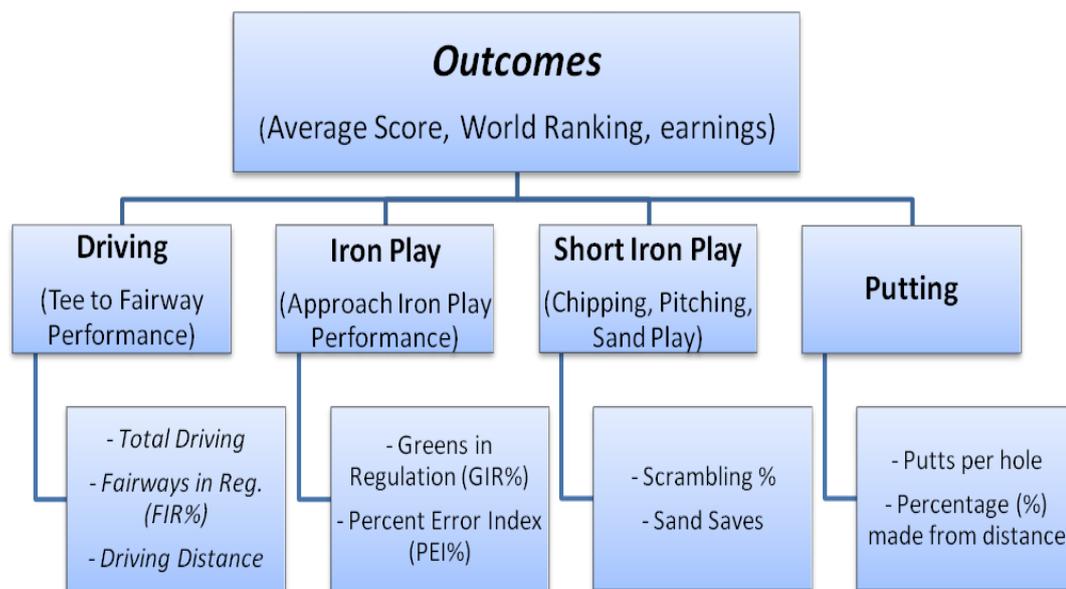


Figure 1.1 Multi-factorial construct of performance in golf.

1.2 Definition of On-Course Skill Components and their Performance Indicators

As stated above, the focus of this doctoral investigation centres on approach-iron performance in golf. Whilst the remaining three on-course skill components shown in Figure 1.1 are beyond the scope of this doctoral investigation; for completeness they are briefly reviewed in section 1.2.1 and some example PI's are provided prior to providing a review on approach-iron play in section 1.2.2.

1.2.1 *Driving, Short-Iron Play and Putting*

Currently, the most appropriate method of analysing on-course driving performance is through a PI termed ‘total driving’ (Jimenez & Fierro- Englehard, 1995; Hernandez, 1999; Hellstrom, 2009). This PI has been created to provide a representation of both driving accuracy and driving distance and is calculated by multiplying the average driving distance in a round by the percentage of cases (expressed as an indice) the ball stops on the fairway. Total driving has been shown in previous studies to display greater levels of association with overall performance when compared with other commonly reported measures such as ‘driving distance (m)’ or ‘driving accuracy (%)’ (Belkin *et al.*, 1994; Finley & Halsey, 2004; Wiseman & Chatterjee, 2006). Despite being reported as a PI in several studies ‘driving distance’ alone has been shown to be a relatively weak predictor of performance (Belkin *et al.*, 1994; Dorsel & Rotunda, 2001; Finley & Halsey, 2004).

In golf, the term ‘short game’ typically refers to wedge, bunker and pitch shots as well as chipping and putting. However, such a definition is quite broad and makes it difficult to analyse performance accurately. A more specific definition, ‘short-iron play’, (defined as shots played from < 50 m to the pin, but not inclusive of putting) has been purported and also shown to be of importance to performance in tournament play (Pelz, 1999; Hellstrom, 2009). Similar to approach-iron play (see section below), limited data exists on short-iron play, particularly when examined in isolation from putting (Hellstrom, 2009). However, in line with the definition above and for the purposes of this thesis I have separated these two components and discussed putting separately. ‘Sand saves’, the percentage of time that a hole is reached in two shots or less from a greenside bunker, has been linked to performance in some studies (Jones, 1998; Finley & Halsey, 2004). Also, ‘scrambling’, the ability to make par when missing greens in regulation

(GIR) has shown high correlation with performance (Larkey, 1994). However it should be noted that both these PI's also potentially include elements of putting in their calculation, thereby limiting their use in isolation also.

Evidence suggests that better players also differentiate themselves from their counterparts through better putting performance (Dorsel & Rotunda, 2001; Hellstrom, 2009). For example, the on-course PI 'Putts per GIR' has shown to be significantly and positively correlated with average score (Dorsel & Rotunda, 2001; Wiseman & Chatterjee, 2006; Hellstrom, 2009). This statistic refers to the average number of putts taken by a player per hole on holes where they have also achieved GIR. However, this variable also considers approach-iron play so it is less useful in examination of putting performance in isolation. Whilst a large number of statistical parameters relating to putting are reported on the major professional golfing tours, no specific measures have been agreed upon to encompass this construct of golfing performance. Therefore, the development of a specific PI that considers putting separate from other on-course components is essential to ensure accurate assessment of this particular skill and thus has been recently been attempted by golf researchers (Marquardt, 2008; Fearing *et al.*, 2011).

1.2.2 Approach- Iron Play

For the purpose of this thesis, approach-iron play has been defined as inclusive of all shots played from a distance ≥ 50 m to the intended target (i.e. the hole located on the green). When performing an approach shot a golfer may use a variety of iron clubs however, their eventual club selection will be dependent upon a number of factors. For example, whilst the most obvious consideration relates to the distance the player is located from the flag, they may also need to account for environmental conditions, tactical strategy (the player may not actually aim to land the ball directly at the hole in some instances) and course design (such as the hardness of the green or landing location) as

well as the difficulty of the pin position. However, previous research has shown that the ability of a player to hit their approach shot closer to the hole significantly increases the chances of one-putting rather than two-putting (James, 2007; Fearing *et al.*, 2011), thereby also increasing the likelihood of recording a low score. Consequently, it is well accepted that the ability to hit approach shots with high accuracy is of great importance to the high-level golfer (James & Rees, 2008; Hellstrom, 2009; Broadie, 2010). It is therefore not surprising that this skill is one of the most practiced skills by players of a variety of abilities (Cochran & Stobbs, 2005; Broadie, 2010).

Despite these considerations, there has been a distinct lack of research into a) the statistical importance of approach-iron play shots and b) their relative contribution to the individual player's golfing performance to date. An example relates to the most commonly used approach-iron play statistic, known as GIR (%) (Belkin *et al.*, 1994; Finley & Halsey, 2004; Wiseman & Chatterjee, 2006). This PI refers to the proportion of times throughout either a single round, or a tournament, that the ball reaches the putting surface in at least two shots lower than the par for that hole. For example, on a par 4 hole to obtain GIR (GIR is a nominal variable) a player would need to reach the green in three shots or less, whilst for a par 4 it would be in two shots or less.

More recently, there has been some support for the use of the percent error index (PEI) as a preferred measure to GIR as a more appropriate PI relating to approach-iron play (Pelz, 1999; James & Rees, 2008). The main reasoning behind this increased popularity would appear to be related to the ability of this statistic to provide more detailed feedback relating to the quality of each actual shot. The PEI of a shot is calculated by determining the distance the ball finishes from its intended target (the hole) divided by the distance from the target (Pelz, 1999). An example relating to how PEI is calculated has been presented in Figure 1.2.

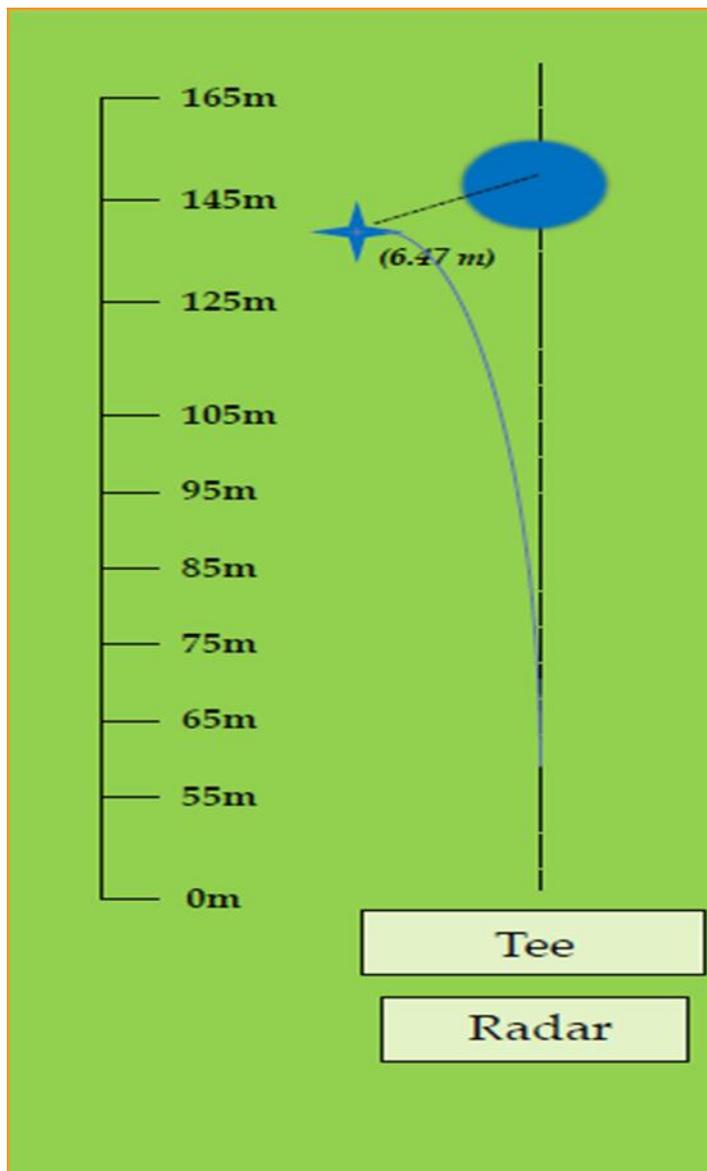


Figure 1.2 Example of percent error index calculation from an approach-iron shot

In this example, the shot has been played 147 m from the pin and finishes 6.47 m to the left and short of the target (hole). Therefore, the PEI for the shot would be calculated as 4.4% ($6.47 \text{ m} / 147 \text{ m} * 100$). Whilst not only providing more detailed information than the GIR statistic, the PEI can also be generated for each club the player uses which then allows for both between-club and between-distance comparisons. This permits players to obtain information on which club(s) and distance(s) they achieve more accuracy (or less error) with, which in turn, has implications for actual game play strategy, as well as

longitudinal performance analysis. Existing data from the United States Professional Golfers Association (US PGA) tour shows that approach shots between 140 and 220 metres actually display relatively similar PEI's for both top and lower ranked tour players (around 4% to 5.5%) (James & Rees, 2008). An observation of more recent statistics from the US PGA Tour in 2012 (www.pgatour.com/stats) however shows that PEI may in fact show greater differentiation between the best and worst performed players. Specific examples of note include the 90-115 m distance category (PEI = 3.97% to 6.46% from best to worst performed), 135-155 m (PEI = 5.0% to 7.78%) and 200-225 m (4.89% to 10.67%). Shots played from the rough however, typically show increased PEI values (normally between a 2% to 6% increase from a player's typical value from the fairway) indicating the increased difficulty of this skill (James *et al.*, 2006; James & Rees, 2008). Shorter shots (such as those associated with a pitching wedge or 9-iron) are synonymous with increased errors either long or short of the target, as opposed to directional errors (James & Rees, 2008).

1.3 Quantification of Performance Indicators in Golf

Performance indicators in golf have a considerable history of being reported and examined in the media as well as in research, (Dorsel & Rotunda, 2001; Fearing *et al.*, 2001; Broadie, 2012) with investigation into their relative importance extending back decades (Pelz, 1999). A preliminary search into the information gathered and reported on players competing on some of the world's major golf tours reveals a plethora of statistics available (see www.pgatour.com/stats for further examples).

Additionally, a variety of technologies are also now available to the average player for the purposes of obtaining such statistics. Laser rangefinders, which are utilised by the participant to reflect a laser signal off the pin (or any other target of interest to the player)

can provide distance measurements in almost real-time to the user. They also have the advantage of being relatively cheap, lightweight and thus portable. Additionally, GPS devices, often including software depicting course layouts and maps displayed on smart phones, is experiencing considerable popularity amongst players for similar reasons.

In further facilitating the demand for more specific game analysis, in 2001 the US PGA began utilising the ShotLink program (*CDW, USA*), a computerised system developed to store and analyse various on-course PI's for players on both the US PGA Tour and the US Nationwide (*Web.Com*) Tour (*James, 2007*). As golfers themselves are not permitted to use any form of measurement device during tournaments to ascertain information (i.e. distance to the pin), this system substantially increased the amount of information available to players, coaches, the media and fans in a post-hoc format. The system operates by utilising hundreds of volunteers recruited during sanctioned tournaments operating devices including GPS and laser range finders to quantify on-course data such as the distance and accuracy of shots, as well as a multitude of composite statistics including those mentioned in Section 1.2 of this thesis.

Despite these improvements in access to relevant data, a number of limitations relating to the usefulness of such systems remain. Firstly, this massive collection of information reporting is not available for the majority of players, with only the US-based professional tours providing players with such detailed data regularly. Secondly, undertaking such an exercise requires a considerable number of volunteers combined with regular access to the relevant technology and devices. Therefore, implementing such an approach on other professional golf tours would most likely require an increase in funding and may not be affordable or feasible. Whilst these two limitations alone illustrate the large number of players with no access to such a service, it should also be noted that this system is not designed to be tailored to individual player needs and is more for the

purposes of media coverage and fans. Therefore, due to the large amount of data being collected and reported, there is a possibility that it may be difficult to isolate those statistics exerting the largest influence over a player's performance; therefore a proportion of these data categories may be redundant.

Web-based software programs, which allow the user to input data relating to their tournament performance based on self-reported measurements have also been developed in recent times (James & Rees, 2008). Based on information collected in on-course tournament scenarios, these programs then produce reports and summaries designed to help the user identify strengths and weaknesses of their game, as well as those factors exerting most influence over performance. As a result, the use of the abovementioned systems and software, as well as an increased focus on technology and science in the sport, has led to a large amount of data relating to performance being collected over the last decade (Quinn, 2006; James 2007; James and Rees, 2008). For example, statistical information from these systems may be reported for individual clubs, distances and between-player analyses can be made. These software systems typically operate on a subscription or licensing scenario, where the user or coach pays to utilise the program or software for a given amount of time. Therefore, whilst potentially more time intensive on the part of the player by requiring them to record their own data, this can allow for the collection and emphasis of specific information relevant to their particular game, thereby allowing for individualisation.

ShotstoHole (*ShotstoHole, Australia*) is one such program that has come into recent popularity through both Australia and the United States. This program allows players to enter such data relating to their golfing performance (such as PEI) into a hand held device, smart phone, or printable scoresheet throughout the duration (or at the cessation) of a round. Despite the accuracy and precision of these methods having yet

been determined, it is nonetheless a popular system at the higher end of the sport. For the purposes of this thesis, this software was utilised, in particular for the purpose of tracking both individual and groups of variables longitudinally.

In off-course scenarios, statistical indicators of performance can also be quantified by a range of high-end technologies, including the abovementioned laser rangefinders and GPS systems. More recently however, the development of Doppler radar technology combined with advancements to computer systems has resulted in an increase in use of golf specific launch monitors. Previous research has shown a good level of accuracy and precision for a range of measurements emanating from such devices. Specifically, good levels of agreement between output from radar devices and 3D analysis systems for variables such as club and ball velocity and swing path/plane have been noted (Sweeney *et al.*, 2009; Betzler *et al.*, 2012).

The TrackMan (*Interactive Sports Games, Denmark*) is one such device. This particular launch monitor is a dual doppler-radar based device that tracks a golf ball during the entirety of its flight. The added value of this launch monitor is that it is capable of quantifying swing and ball launch parameters such as club path, swing plane, ball velocity and maximum height and reporting them in close to real-time. It is also able to capture basic information relating to the direction, length and accuracy of a given golf shot and therefore statistics such as PEI can be easily obtained. As it is also the device of choice on the US PGA Tour and generally considered as the gold standard for the purposes of golf shot measurement, the TrackMan device was used wherever possible in this thesis.

1.4 Development of Skill Tests in Golf to Assess Approach-Iron Play

In many cases, information relating to the longitudinal collection of on-course PI's discussed in Section 1.2 may not be available for high-level amateur golfers. Under these circumstances, the use of specific skill tests in controlled conditions off-course may be an alternative method to evaluate the relative strength and weaknesses of these golfers. Skill in sport can be defined as 'the developed ability to ensure optimal results with maximum certainty whilst utilising minimal time, energy or both.' (Knapp, 1972) The structured evaluation of individual skill components in non-competitive environments is commonplace in many team sports such as soccer (Ali *et al.*, 2007; Russell *et al.*, 2010), volleyball, (Bartlett *et al.*, 1991; Gabbett & Georgieff, 2006) and rugby league (Gabbett *et al.*, 2011a; Gabbett *et al.*, 2011b). It has also experienced popularity in its use in individual sports (Vergauwen *et al.*, 1998; Lam & Zhang, 2000; Brent *et al.*, 2009). However, although skill assessments such as the 'National Skills Challenge' have been used in golf over the last two decades (particularly for use with younger players) (Schick, 1983; Collins, 2001), as well as simulated rounds of golf for use in research (Stevenson *et al.*, 2009) there are no skills tests for golf that have been reported in the peer-reviewed literature.

In order for any a) existing or b) newly developed tests to be truly useful in the practical arena and for use in research, it is essential that their measurement properties are assessed and reported.

The benefits of developing skills test specifically for use in golf are numerous. For example, appropriately designed assessments can be used to determine the effectiveness of coaching or scientific interventions. Specifically, researchers have utilised skills tests in other sports investigating the effect to performance of nutritional supplementation (Currell *et al.*, 2009; Duncan *et al.*, 2012), athlete psychology (Bois *et*

al., 2009; McKay & Wulf, 2012) and pre-skill routine (McCann *et al.*, 2001). Utilising skill assessments in this manner provides the researcher with a certain level of experimental control whilst potentially limiting the need to collect longitudinal information based on tournament play similar to that outlined in Section 1.3. Such assessments have also experienced use for the purposes of talent identification in certain sports (Gabbett & Georgieff, 2006; Ali *et al.*, 2011). For example, organised competitions such as the Australian Football League in Australia and the National Football League in the United States utilise testing combines as part of their player recruiting process. More specifically, for the purposes of this thesis it could be hypothesised that such tests would be particularly valuable for identifying high-level amateur golfers who are seeking to become the next generation of touring professionals. Further uses for testing athlete skill outcomes in sport include the ability to identify relative strengths and weaknesses of the performer, in particular when aiming to monitor progress improvements of the performer within a structured training program (Pyke *et al.*, 2000). For golf, this is particularly useful for working with athletes as part of institute programs and/or scholarship holders. Finally, skill tests also have a history of use as a time-efficient method of defining participant ability levels (Bock-Jonathon *et al.*, 2007; Brent *et al.*, 2009) and could potentially be used in golf to assist and inform future handicapping systems.

However, in order for a test to be deemed useful for any of these purposes, it should display appropriate measurement properties. This includes displaying good levels of reliability and validity as well as being feasible within the environment it is being used. To assess the reliability of skill tests in sport, specifically the test-retest reliability should be determined and where relevant, the inter- and intra-rater reliability should also be examined (Streiner & Norman, 2005; Portney & Watkins, 2009). The level of test-retest reliability of a skills test can be determined by repeating the same test, calculating the score in that test, then obtaining indices of reliability such as the intra-class coefficient

(ICC), 95% limits of agreement (LoA) or coefficient of variation (CV%). To assess the validity of a testing instrument, three main components can be considered. The first, content validity (inclusive of logical and face validity), refers to how well a testing instrument/s cover the entirety of content on which the outcome is intending to measure (Haynes *et al.*, 1995; Streiner & Norman, 2005; Portney and Watkins, 2009). In this thesis, a combination of two tests will be used to attempt to explain performance of a player in actual tournament play, thereby investigating this component of validity. A second component for consideration is construct validity, which refers to how well a given testing instrument either links with or measures a theoretical construct it claims to assess (Westen & Rosenthal, 2003; Streiner & Norman, 2005). Therefore, in order for a testing instrument to display a good level of construct validity, the test should discriminate between performers of different ability levels. Such investigations should ideally be undertaken in an environment as similar to actual competition as possible, however not at the expense of experimental control or causing a reduction of reliability. This serves to uphold the representativeness of the testing protocol (McNamara & Collins, 2011; Vilar *et al.*, 2012; Pinder *et al.*, 2013). The third component for specific consideration is criterion-related validity and is inclusive of concurrent and predictive components (Streiner & Norman, 2005; Stinson *et al.*, 2006). Specifically, this refers to the ability of the test to relate well to an already validated measure of the same theoretical construct.

However, the measurement property of particular relevance to this thesis is predictive validity. Whilst similar to concurrent validity, the two can be differentiated typically by the temporal differences in test re-assessment. For example, when developing a testing protocol to assess specific skills in sport, there should ideally be a relationship between the players' score in such a test and their related performance under competition conditions. This performance however may take place in the coming days, weeks or even months following the initial testing session. This serves to establish the test's predictive

validity, which appears to have only been investigated in only a small number of tests of sporting skill (Downs and Wood, 1996; Lam & Zhang, 2002; Brent *et al.*, 2009). Therefore, this undertaking represents a highly original element to the thesis. Development of testing protocols that display predictive validity can allow for investigators, coaches and sporting administrators to utilise test results with a great level of confidence with reference to estimating participant ability levels.

1.5 Objectives of the Thesis

There were two general aims of this thesis. The first aim was to develop two tests for use with high-level amateur players, each assessing different components of the ability to hit approach irons in golf. The measurement properties of each protocol were also assessed. The second aim was to assess how performance in each of these off-course tests related to performance during actual tournament play. The studies included in this thesis as well their overall objectives are listed below.

Chapter 2 – Study I. Development of the Nine-Ball Skills Test to discriminate elite players in golf.

- To develop a valid and reliable assessment of the ability of high-level amateur golfers to shape and control approach iron shots, whilst also maintaining accuracy.

Chapter 3 – Study II. Development and validation of the Approach Iron Skill Test for use in golf.

- To develop a valid and reliable assessment of the ability of high-level amateur golfers to hit accurate approach-iron shots over a range of distances.

Chapter 4 – Study III. An evaluation of high-level player-reported measurement of approach-iron shot distances.

- To determine the precision and accuracy of player-reported shot characteristic measurements by comparing values with those concurrently obtained from known distances.

Chapter 5 – Study IV. Tests examining skill outcomes in sport: A systematic review of measurement properties and feasibility.

- To examine existing skill tests in sport with reference to their methodological quality, reliability, validity, responsiveness and feasibility characteristics

Chapter 6 – Study V. Two tests of approach iron skill and their ability to predict tournament performance in high-level amateur golfers.

- To examine the predictive and convergent validity of the Nine-Ball Skills Test and the Approach-Iron Skill Test in high-level amateur male golfers.

1.6 Limitations and Delimitations

1.6.1 Limitations

- It was assumed that the participants involved in this study were representative of the target population (high-level amateur golfers). To regulate this limitation, stringent inclusion and exclusion criteria were followed.
- Despite the many positive uses of the PEI statistic, it does not provide the investigator with the specific nature of the shot error. For example, an error of 5% could be any one of short/long or left/right of the intended target. Further, PEI

does not take into account the lie in which the shot was hit from (i.e. the fairway, the rough or from the bunker). As a result this factor was controlled for in Study V of this thesis.

- In Study V of this thesis, the environmental conditions during the 90 days of data collection were variable. Whilst there was definite ecological validity and representative design with the structure of this study, it may have potentially been at the expense of some experimental control.
- In Study V differences in course difficulty (dependent on the course being played) were noted over the 90 days of data collection. These factors influenced the decision to undertake a relatively long on-course data collection time for this study.
- There is a growing body of research identifying psychological and tactical factors exerting considerable influence over approach-iron play performance (Finn, 2009; Bell & Hardy, 2009; Bois *et al.*, 2009; Cooke *et al.*, 2010; Cotterill *et al.*, 2010). These factors were not assessed in this thesis and may explain some variance of test scores noted in Study V.
- Finally, with reference to the testing combine, due to the use of technology to measure PEI (Doppler radar), uptake of these protocols may be limited to institutions or learning centres with access to such equipment thereby restricting their widespread use.

1.6.2 Delimitations

- The studies in this thesis involved the recruitment of male high-level amateur and elite golfers aged between the ages of 18-28 years. Therefore, results may not be

generalizable to other sub-groups such as their elite female counterparts or elite, mid-level and novice golfers.

1.7 Significance of the Thesis

There is definite practical relevance with the studies contained within this thesis for both golfers (especially high-level amateurs) and their coaches. Specifically, the development of two tests (i.e. a testing ‘combine’) to assess the ability of these golfers to perform approach-iron shots has definite implications for performance enhancement in the sport. These implications can be further strengthened as a result of considering the ability of these tests to specifically relate to actual tournament performance.

Firstly, players and coaches would be equipped to increase the efficiency of practice and coaching through access to specific information produced by tests developed in this thesis. Currently, in order for a player to obtain an accurate and reliable representation of their aptitude in each on-course skill component, longitudinal data needs to be collected and interpreted in a format similar to that undertaken in Study V of this thesis. A time efficient, reliable and valid technical skill assessment protocol would potentially provide such information to the player in a much shorter time period. Validation of such a protocol through the examination of scores from players of differing playing ability allows for a simple, time efficient method of identifying contrasting standards of play and could also be useful in the golf handicapping process with players of lesser ability than used in this study. The protocol may also have implications in examining the effectiveness of existing programmes currently operating in state and national golf institutions/centres of learning, as it incorporates players of a similar ability. Detailed investigation into player performance when performing from different distances and with different clubs within the protocol could lead to more accurate analysis

of strong aspects of a player's game, as well as identifying those needing to be made a priority in practice. This would be valuable for use in learning environments, allowing coaches to increase the effectiveness of their teaching. The protocol could also form part of talent identification programs currently in existence in high-level amateur golf. Comparisons of between-round participant performance in the testing combine could allow for an improvement in the efficiency of existing practice habits undertaken by players.

1.8 References

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CHAPTER 2 – Study I

Development of the Nine-Ball Skills Test to discriminate elite and high-level amateur golfers

The chapter is unavailable in this version of the thesis.

The chapter has been published as:

Robertson, S. J., Burnett, A., Newton, R., & Knight, P. (2012). Development of the Nine-Ball Skills Test to discriminate elite and high-level amateur golfers. *Journal of Sports Sciences*, 30(5), 431-437. DOI: [10.1080/02640414.2012.654398](https://doi.org/10.1080/02640414.2012.654398)

CHAPTER 3 – Study II

Development and validation of the Approach-Iron Skill Test for use in golf

The chapter is unavailable in this version of the thesis.

The chapter has been published as:

Robertson, S. J., Burnett, A. F., & Newton, R. (2013). Development and validation of the Approach-Iron Skill Test for use in golf. *European Journal of Sport Science*, 13(6), 615-621.

DOI: [10.1080/17461391.2012.757809](https://doi.org/10.1080/17461391.2012.757809)

CHAPTER 4 – Study III

An evaluation of high-level player-reported measurement of approach-iron shot distances

The chapter is unavailable in this version of the thesis.

The chapter has been published as:

Robertson, S.J., & Burnett, A.F. (2013). An evaluation of high-level player-reported measurement of approach-iron shot distances in golf. *International Journal of Sports Science and Coaching*, 8(4), 789-800. DOI: [10.1260/1747-9541.8.4.789](https://doi.org/10.1260/1747-9541.8.4.789)

CHAPTER 5 – Study IV

Tests assessing skill outcomes in sport: A systematic review of measurement properties and feasibility

The chapter is unavailable in this version of the thesis.

The chapter has been published as:

Robertson, S. J., Burnett, A. F., & Wilkie, J. (2013). Tests Examining Skill Outcomes in Sport: A Systematic Review of Measurement Properties and Feasibility. *Sports Medicine*, 44(4), 501-518.
DOI: [10.1007/s40279-013-0131-0](https://doi.org/10.1007/s40279-013-0131-0)

The open access PDF version of the paper is also [available at Research Online](#), Edith Cowan University's Repository.

CHAPTER 6 – Study V

Two tests of approach-iron golf skill and their ability to predict tournament performance

The chapter is unavailable in this version of the thesis.

The chapter has been published as:

Robertson, S., Burnett, F. A., & Gupta, R. (2014). Two tests of approach-iron golf skill and their ability to predict tournament performance. In *Journal of Sports Sciences*, 32(14). 1014-1028.

DOI: [10.1080/02640414.2014.893370](https://doi.org/10.1080/02640414.2014.893370)

The open access PDF version of the paper is also [available at Research Online](#), Edith Cowan University's Repository.

CHAPTER 7– DISCUSSION AND CONCLUSIONS

7.1 Introduction

Golf is an extremely popular and international sport which is played by participants of a wide variety of ability-levels. Despite this, no assessments of skill outcomes in the sport appear to currently exist within the peer-reviewed literature. This is despite such tests having a history of use and investigation in both team (Gabbett & Georgieff, 2006; Ali *et al.*, 2007; Sunderland *et al.*, 2007) and individual sports (Vergauwen *et al.*, 1998; Bottoms *et al.*, 2006; Brent *et al.*, 2009). Such assessments of skill outcomes have considerable use in both practical and research domains. For example, skill tests can be used as outcome measures in coaching and scientific interventions (Currell *et al.*, 2009; Duncan *et al.*, 2012; McKay & Wulf, 2012), as part of talent identification programs (Gabbett & Georgieff, 2006; Vaeyens *et al.*, 2008; Ali, 2011;), as a method to monitor athlete development longitudinally (Pyke, 2000) and as time efficient methods of defining participant ability-levels (Brent *et al.*, 2009).

In golf, the ability to drive the ball from the tee, hit accurate shots close to and around the green, and display a high level of putting ability are all skills required in order to perform well in the sport (Hellstrom, 2009). In particular, the ability to hit a shot close to the pin using a lofted iron club (Approach-Iron Play) has been shown to be of considerable importance to golfers of a variety of ability-levels (Broadie, 2008; James & Rees, 2008; Broadie, 2012). Despite some performance analysis research being undertaken into this area (Belkin *et al.*, 1994; Wiseman & Chatterjee, 2006; James, 2007; James & Rees, 2008;), developments are limited due to no clearly defined measure of approach-iron ability being available. Further, methods in which to assess this skill in the off-course environment are also not well-established.

Additionally, although sporting physical performance tests have undergone recent review in the literature (Currell & Jeukendrup, 2008; Ali, 2011), no specific reviews exist relating to tests of sporting skill. In particular, essential characteristics relating to design of tests examining skill outcome as well as the measurement properties (inclusive of reliability, validity & responsiveness) and feasibility of such skill tests have not been stated. Research is particularly lacking in the reporting of predictive validity and feasibility of these tests. These measurement properties should also be assessed as part of their design through the use of appropriate statistical procedures and methods in order for them to be considered truly useable for purposes stated above. It is the direct consideration of these gaps in the literature and coaching and sports science practice that has initially stimulated, and eventually led to, the undertaking of this doctoral investigation.

7.2 Summary and Conclusions

There were two overarching aims of this thesis. The first aim was to develop two tests (Nine-Ball Skills test and the Approach-Iron Skills test) that assessed two different components of players' ability to perform approach shots in golf. The reliability and validity of these assessments was investigated by recruiting both elite and high-level amateur golfers in Study I and II. The second aim was to assess how performance in these off-course tests related to performance during actual tournament play (Study V). Studies III provided evidence behind validity of outcome measures and Study IV helped inform the approach behind Study V. The specific aims and results relating to each of these studies have been briefly outlined below.

Study I – Development of the Nine-Ball Skills test to discriminate elite and high-level amateur golfers

The primary aim of the first study in the thesis was to develop a specific approach-iron golf test, the Nine-Ball Skills Test, for use with high-level amateur and elite level golfers. Further, both the discriminative validity and test-retest reliability of the test were also investigated in these players. If shown to be valid and reliable, this would help create a practical assessment tool for coaches and players to utilise in the field as part of training and performance analysis. It could also have application for the purposes of talent identification and in junior development pathways.

The test was developed to specifically assess the ability of a player to shape and alter the height and trajectory of the ball when performing an iron shot, whilst also maintaining a low level of shot error. For the purposes of this study, shot error was defined as the distance a shot misses its target divided by the distance at which the shot was hit from. This form of error in golf is defined as Percent Error Index, or 'PEI' (Pelz, 1999). Results from this study showed that the test displayed an ability to differentiate between the two groups of players utilised in the study hence displayed good discriminative validity. In particular, elite level players showed a greater ability than high-level players in performing draw shots (shaping the ball from right to left for a right-handed player) across all three height categories. An examination of the assessments' test-retest reliability revealed only fair results. Consequently, it was recommended that the test be standardised using two rounds. The development of this test represented the first of its kind for the sport of golf.

Study II – Development and validation of the Approach-Iron Skill test for use in golf

This study detailed the development of a second golf approach-iron play assessment, referred to as the ‘Approach-Iron Skill Test’. The primary aim of this study was to determine the discriminative validity and test-retest reliability of the Approach-Iron Skill test for use with elite and high-level amateur players. Specifically, this test aimed to assess the ability of players to perform accurate straight approach-iron shots from multiple distances, which was hypothesised as a component of approach-iron play to that used in the first study. The secondary aim of this study was to determine whether between ability-group differences existed for absolute error from the target (m) as well as the error of shots normalised for hitting distance (PEI).

Specifically, the test included the assessment of player’s ability to hit nine shots from distances ranging between 55 m and 165 m. A total of 27 shots were hit with as three shots were played from each of these distances. Two rounds of the test were undertaken. The test displayed very good test-retest reliability as well as showing a clear ability to discriminate between both elite and high-level amateur players. In particular, the study showed that for several distances (65, 95, 145 and 165 m) elite players showed significantly lower PEI values and absolute shot error (m) than high-level amateurs. As a result of these findings, the Approach-Iron Skill test can be deemed a suitable assessment to assess approach-iron play in elite and high level amateur golfers.

Study III – An evaluation of high-level player-reported measurement of approach-iron distances

In golf, there is a need for accurate measurement of both individual shot distances and shot accuracy by high-level players. This ability is important so that the correct club can be chosen to hit a forthcoming approach shot, as well as for the purposes of informing decision making and course strategy. Further, this is important for the purposes of performance analysis.

This study aimed to determine the accuracy and precision of self-report shot distance estimations in high-level golfers throughout a round of competitive golf. This was undertaken by obtaining multiple measurements collected on course by a group of high-level amateur players and comparing these values with distances concurrently obtained from a laser range finder (long distances on the fairway) and steel tape measure (short distances on and around the green). Four variables were compared as part of the study, these being; a) Distance to Hole (distance to the hole, predicted prior to undertaking the shot), b) Approach-Shot Distance (predicted distance of the shot itself) and c) Ball to Hole Distance (predicted distance remaining to the hole following completion of the approach shot) and d) PEI (consisting of the second and third variables).

Results from this study showed good levels of agreement between self-reported player estimates and known distances for all four variables. In particular, Distance to Hole, Approach-Shot Distance and PEI were shown to be generally accurate and precise across both short and longer distances. Ball to Hole Distance however, showed some significant decreases in measurement accuracy and precision for estimations made further from the hole. Some between-player variation was noted for these variables indicating a potential need for further training for specific individuals.

The results of this study provide justification for the use of such information in longitudinal performance analyses as well as assisting with on-course decision making. Based on these findings, high-level amateur players can utilise such estimations with confidence.

Study IV – Tests examining skill outcomes in sport: A systematic review of measurement properties and feasibility

Tests assessing skill outcomes in sport are commonly used by coaches and researchers to assess an athlete's level of skill or ability, evaluate the effectiveness of interventions and for the purpose of talent identification (Gabbett & Georgieff, 2006; Ali *et al.*, 2008; Currell *et al.*, 2009). However, many have not had their measurement properties (i.e. reliability, validity, responsiveness) or feasibility assessed. The aim of this study was to systematically review the measurement properties and feasibility characteristics of sporting skill outcome tests reported in the peer-reviewed literature. This study was conducted to help inform the general approach used in Study V.

A total of 22 studies met the inclusion/exclusion criteria and each of these studies was assessed on a customised checklist of criteria based on previous review templates from other disciplines (Stinson *et al.*, 2006; Moher *et al.*, 2009; Mokkink *et al.*, 2010). A range of sports were the subject of the 22 studies included in this review, however, only seven examined individual sports. Elite athletes were most commonly investigated and only one study investigated females in isolation of males. A range of methods and statistical procedures were used by researchers to determine the measurement properties of their skill outcome tests, thereby making direct comparison of studies difficult. Test-retest reliability was determined in all but one of the reviewed studies, whilst most

investigated at least two aspects of validity (i.e. content, construct or criterion-related validity). However, a distinct lack of specific investigation was noted with regard to predictive validity and responsiveness. Further, whilst some aspects of feasibility were detailed in over half of the studies, practicality and limitation considerations of undertaking the related tests were generally not formally investigated. It was also recommended that future researchers implement a formal, methodological approach to assessing feasibility. Consideration of study characteristics, measurement properties and feasibility components assessed in this review can assist future researchers when developing or modifying tests of sporting skill outcomes.

Study V – Two tests of approach iron skill and their ability to predict tournament performance in high-level golfers

Despite the Nine-ball Skills Test (Study I) and the Approach Iron Skill Test (Study II) both being investigated for their test-retest reliability and discriminative validity in high level and elite golfers, their relationship with a) each other and b) actual on-course tournament performance has not been investigated. Therefore, the aim of this study was to examine both the convergent and predictive validity of the Nine-Ball Skills test and the Approach-Iron Skills test. This study was conducted in a group of high-level amateur male golfers.

Over consecutive days, a group of high-level golfers performed both tests. Over the subsequent 90-day period, the same group of players completed a minimum of 10 rounds of tournament play, whilst reporting PEI, distances in which the shot was performed from as well as the lie of the ball. These and other data were recorded using self-reported player software (ShotstoHole) designed for the purposes of individual player

performance analysis. Results showed a moderate but significant correlation between player scores in both tests. Further, generalised estimating equations using the lie of the ball and distance to hole as covariates were undertaken to determine the amount of explained variance in tournament PEI. From these analyses it is likely that each of the two protocols assess differing components of the performance construct, approach-iron play. Further, it was revealed that the Approach Iron Skills test was the stronger predictor of on-course PEI and when both test scores were considered in a model, a minimal amount of additional variance of on-course PEI was explained. These findings justify the use of the Approach-Iron Skill test to predict tournament approach iron performance in high-level golfers.

7.3 Practical Implications of the Research

The broad theme of this doctoral thesis focuses most specifically on the practical problem of improving golf performance. This is particularly in relation to the elite and high level amateur golfing populations. Results emanating from this thesis should inform, challenge and in some cases, alter existing methods currently utilized in the practical domain in golf and potentially other sports.

The development of two separate skill tests as undertaken in this thesis can provide those working in the field with robust, standardized tools with which to assess players on their ability to perform approach-iron shots. Results stemming from Study V illustrate the ability of the two tests developed in this thesis to assess different components of the same golf performance construct that being, Approach-Iron Play. Whilst it may be preferable to develop a protocol that assesses these different components within the same test, this may not always be possible and as such there is support for similar approaches being undertaken in different disciplines (e.g. marketing – see Bergkvist & Rossiter,

2007). Researchers working in other sports may choose to employ similar approaches, depending on a) the complexity and b) the number of skill actions required in the sport.

The comprehensive investigation into the measurement properties of these two tests in Studies I, II and V allows for them to be used for the purposes of research. In particular, in future golf research, the tests may be suitable as an outcome measure in a range of interventions relating to the sports science disciplines. In particular, an examination of each test's ability to relate to actual tournament play should be standard in future work in this area. Within this thesis, the use of statistical techniques to account for correlated (or clustered) data allowed for these relationships to be specifically investigated and may be useful for other investigators with access to collecting performance analysis data in a longitudinal manner.

A consideration of the measurement properties assessed in a collection of studies (in particular, Study IV) should also serve to provide some guidance for other researchers relating to statistical approaches suitable for use in this specific area. Whilst numerous methods can, and will, continue to be used to examine relationships in sports performance research, a number of approaches undertaken here could be considered novel to the discipline, in particular those employed in Study V. Additionally, despite numerous forms of tasks, tests and experimental protocols being developed in sports performance research, very few investigate the totality of measurement properties outlined in Study IV. As such criteria were largely based on the rigorous processes commonplace in other disciplines (Streiner & Norman, 2005; Portney & Watkins, 2008; Moher *et al.*, 2009; Mokkink *et al.*, 2010), these should warrant consideration by researchers currently working in this area. Specifically, addressing these criteria may serve to provide a guide for future researchers in developing new testing protocols. The importance of developing tests displaying these qualities with reference to their specific use for the purposes of talent identification should

also be noted. A lively debate has surrounded the use of testing protocols for these purposes of late, with much of this discussion centred on the representativeness of testing protocols currently used in certain sports (Kingsley *et al.*, 2012; McNamara & Collins, 2012; Vilar *et al.*, 2012; Pinder *et al.*, 2013). However, despite the importance of such a test characteristic, the importance of focusing on the measurement properties outlined in Study IV should not be overstated (Bartlett, 2008). Devising a representative protocol that displays poor measurement properties renders such a test as unusable for a number of purposes.

7.4 Limitations of the Doctoral Investigation

Firstly, female golfers were also not examined in this thesis. The golfers utilized in these studies were categorized as being of a ‘high-level’ and therefore, the results may not be generalizable to players of either higher (world-class) or lower ability (mid to high handicap) levels. It is also unlikely that shaping and controlling the height of the ball is an ability developed or even learnt by lesser skilled players and therefore, the tests developed in this study may not be appropriate for golfers of lesser ability. As both of the tests developed in this thesis utilized a form of radar technology to measure the characteristics of each shot, they are unlikely to be suitable for players without access to such equipment.

It should also be noted that despite its clear advantages over other previous measures of Approach-Iron ability, PEI itself is still not without its limitations. For example, it does not take into account the lie of the ball prior to the shot being played (i.e. the shot difficulty), or the nature of the shot error (left/right or short/long of the target). Hence, this consideration of ball lie was used as a controlling factor in the analyses

undertaken in Study V. Additionally, considering it uses the pin or flag as its reference point for accuracy, it is presuming that the player is aiming to land the ball close to this target; in some cases due to course strategy a player may intentionally aim away from this target. Finally, PEI in the skills tests was not based on the bounce and roll distance.

With reference to the earlier studies undertaken in this doctoral investigation, the long term temporal stability of the two developed testing instruments was not examined. This was largely due to logistical issues related to player access. Additionally, in Study V of this study thesis, during the on-course data collection phase, environmental conditions were variable. Further, the difficulty of both the courses and competitive field (level of fellow competitors) was variable throughout this 90-day period.

Relating to the TrackMan™ unit, whilst previous research has investigated the validity of some parameters reported by this device (Betzler *et al.*, 2012), no data relating for the two utilised in this thesis has been presented. The parameters ‘carry’ (distance a shot has been hit, neglecting ball bounce and roll) and ‘side’ (carry distance left or right of the intended target) used to calculate PEI values in this study specifically warrant attention in future. It could also be hypothesised that the reliability and validity properties reported in the tests presented in this thesis may have been affected in some way by the measurement error contained within the device.

7.5 Future Research Directions

This research has successfully developed valid and reliable methods of assessing approach-iron play in off-course situations, whilst displaying clear relationships with actual tournament play data. However, more work needs to be undertaken to undertake

similar investigations with the remaining performance sub-components of golf such as hitting from the tee (driving), short game (chipping, wedge and sand play) and putting.

Further, whilst these initial results are positive, future research may look to improve the representativeness and feasibility of the protocols developed in this thesis. For example item reduction techniques such as Rasch Analysis or concept retention (i.e. Beaton *et al.*, 2005) may help decrease the time of administering the tests. However, it should be stated that this should be done without compromising the generally positive measurement properties displayed. Despite this, the tests may also be used in other research into golfing skill, relating to coaching, motor learning, as well as physical and/or psychological interventions.

In Study V, although the use of 10 rounds to assess tournament performance in PEI was well justified, future work may look to investigate an exact number of rounds required in order to obtain a true representation of a players' ability in this area (i.e. how many rounds are required before the values show stability?). This may lead to decreased participant burden in the on-course analysis component of testing. Additionally, from a performance analysis perspective, the sensitivity and relative importance of PEI (and other performance indicators) to overall performance (i.e. overall score) for both individual players and larger population groups may also be of future interest.

Finally, it is hoped that the measurement properties and feasibility considerations identified and investigated in Study IV serve as a guide for future authors working in this area. Future research may look to develop formalized guidelines for authors for specific use in sports science, as has been undertaken in both the health (Moher *et al.*, 2009) and medical fields (Mokkink *et al.*, 2010).

7.6 References

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