TIME MOTION ANALYSES OF ONE-DAY INTERNATIONAL AND TWENTY/20 MATCHES AND THE DEVELOPMENT OF A SIMULATED BATTING PROTOCOL SPECIFICALLY DESIGNED FOR FEMALE CRICKET PLAYERS

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Abstract

Background: Accurate and reliable in-game data is fundamental when designing effective batting training. A simulated batting protocol that could aid research and training has not been specifically designed for female cricketers because of a distinct lack of empirical in-game data for the women's version of the game. **Objective**: The purpose of this study was to quantify the motion demands and run-breakdown of a century and T20 half-century for women's cricket matches to establish a simulated batting protocol specifically designed for female batters. **Method:** Time-motion analyses of four one-day international and six T20 innings were conducted on international cricket matches played around the world between 2012 and 2017. The innings was divided into the bowling and batting innings. The ODI innings that met the criterion of 100 runs scored and T20 innings with scores above 50 runs were used in the run breakdown, which included scores from the top 10 countries ranked by the ICC. The time-motion analyses and century breakdown were utilised in the establishment of a simulated batting protocol. The simulated batting protocol for female batters was created/developed by utilising the method designed by Houghton *et al.,* (2011), who developed the BATEX© protocol. **Results:** The time-motion analyses indicated that the mean duration of an ODI innings was 169 minutes. An over lasted 2.45 minutes, with 24.86 seconds between each delivery and 55 seconds between each over. When the bowling side changed to a new bowler, it was 1.12 minutes between overs**.** The mean score for the first power play in an ODI was 41 runs with 1.38 wickets being taken. The mean score during the second power play was 28 runs with 0.714 wickets being taken. The T20 bowling innings lasted 75.50 minutes, with an over lasting 2.52 minutes with 25.58 seconds between deliveries. The mean score in the T20 batting innings was 122 runs. During the power play, which lasted 24.35 minutes, 37 runs were scored with 1.45 wickets being taken. The simulated batting innings was then designed as four stages lasting the duration of a typical women's century. Each stage was based on theoretical phases of play that may occur during a batting innings. **Conclusion:** The study indicated that the women's game has different movement requirements compared to the men's game in both the ODI and T20 formats. Further, the demands differ depending on the country that is playing. A training and research protocol specifically designed for female batters is an important outcome.

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Publications

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3. Munro, CE and Christie, CJ. Lack of research in women's cricket. *Exercise Science and Sports Medicine Research Collaboration*, Cape Town, South Africa, 1 December, 2017.

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CHAPTER I

Introduction and scope of research

1.1 Introduction

Women's cricket has been played for over 100 years (Odendaal, 2011). It is only in the past few decades, however, that the women's game has expanded and been embraced by a variety of nations all around the world (Odendaal, 2011; Koley & Kashyap, 2010). Initially, women's cricket took the form of test matches played over three days, but this was increased to four days in 1985 (Harris, 2005). The game now includes one-day international cricket (50-over games), and more recently, the Twenty/20 (T20) format. This has resulted in a greater number of international matches being played all over the world (Koley & Kashyap, 2010). In terms of competition at an international level, women's cricket is still a relatively recent game. It is, therefore, not surprising that the number of studies focusing solely on women's cricket is limited.

A large proportion of the studies on women's cricket have been limited to Australian fast bowlers. These studies considered injury prevalence (Perera, Kemp, Joseph, Kountouris, & Finch, 2017; Stuelcken, Ferdinands, & Sinclair, 2010; Stuelcken, Ginn, & Sinclair, 2008b), basic anthropometric measures (Koley & Kashyap, 2010; Stuelcken, Pyne, & Sinclair, 2007) and the biomechanical demands of fast bowlers (Savage & Portus, 2002; Stuelcken, Ferdinands, Ginn, & Sinclair, 2010). For other aspects, such as batting, fielding, and wicket-keeping, there is no known published research to date. It is speculated that empirical data is taken from men's matches and applied to the women's game. This cannot give a fair or true reflection of the workloads placed on female cricketers especially because men and women differ with respect to their morphological and physical characteristics (Koley & Kashyap, 2010; Stuelcken *et al*., 2007) such as strength, power, physical capabilities and the tactics they implement during a game. As a result, different training strategies and research methods are required for the two sexes (Savage & Portus, 2002; Stuelcken *et al*., 2008b).

Owing to the need for increased crowd attendance and general entertainment for the viewers, limited-overs cricket was introduced in both the men's and women's leagues.

This format consists of 20 overs of fast-paced cricket, promoting more boundaries, and has resulted in the need for better-trained batters (Houghton, 2010; Petersen, Pyne, Portus, & Dawson, 2008; Petersen, Pyne, Portus, & Dawson, 2009). In addition to the increased frequency of cricket matches played throughout the year, there is also increased pressure to perform at a high level consistently (Noakes & Durandt, 2000). This, in turn, increases the risk of fatigue and injury for all players. With specific reference to batters, Petersen and colleagues (2010) highlighted that male batters would be required to decelerate their body mass several times in a match situation (Petersen, Pyne, Dawson, Portus, & Kellett, 2010). These decelerations increase the eccentric demands placed on the lower limbs, and when done repeatedly, result in irregular neuromuscular fatigue (Noakes & Durandt, 2000). In both short-duration and prolonged batting periods, fatigue induced through repeated eccentric muscle actions results in slower sprint times, impaired neuromuscular function and reduced batting accuracy in men (Christie, 2008; Houghton, Dawson, Rubenson, & Tobin, 2011; Pote & Christie, 2013). During competition, these performance decrements can lead to the loss of a wicket (Houghton, Dawson, Rubenson, & Tobin, 2011; Noakes & Durandt, 2000). Despite this, research into the physiological demands of batting is limited, and research like this has not been done on female batters.

Batters alter their intensity of effort depending on the circumstances, different phases of the game (Noakes & Durandt, 2000) and perception of effort (Pote & Christie, 2016). One example of this would be the scoring of an one-day-international (ODI) century (Pote & Christie, 2016). Although scoring a century is an achievement to which every batter aspires, there are very few centuries scored in women's cricket. In the 2015/2016 season, considering the top 10 countries, only 11 ODI centuries were scored in the women's league compared to the 91 ODI centuries scored in the men's league (Cricinfo: Date accessed: January 2018). Furthermore, the frequency of games played in the men's league throughout the season is higher than that of the women's league (Cricinfo: Date accessed: 25 January 2018). Nevertheless, this is changing, with the number of women's matches and centuries scored increasing in the 2016/2017 season. A total of 67 matches were played (excluding small tournaments) during which 23 centuries were scored. (Cricinfo: Date accessed: 25 January 2018).

The physiological and biomechanical demands placed on the batter increase the longer the batter is at the crease, especially when scoring a century (Christie & Pote, 2014; Houghton *et al*., 2011; Pote & Christie, 2016). The need to quantify or at least estimate this demand is important to determine the best training methods to use to prepare batters for all types of competition. A simple and effective way to achieve this is by using time–motion analyses, break-downs of centuries scored and simulated batting protocols. Time-motion analysis in cricket batting emerged in the mid to late 20th century (Noakes & Durandt, 2000) and in recent years, there have been several motion-analysis studies performed on male cricketers (Duffield & Drinkwater, 2011; Houghton *et al*., 2011; Petersen *et al*., 2009; Rudkin & Donoghue, 2008). These studies observed movement patterns during batting, bowling, and fielding. The most recent study by Duffield and Drinkwater (2011) investigated the physiological demands of scoring an ODI century. The authors reported that the average male batter spent, in total, over two hours standing, one-hour walking, five minutes jogging and several minutes performing high-intensity exercise in short intervals.

When scoring an ODI century, a male batter runs an average of 40 singles, eight twos, three threes and hits an average of seven fours and two sixes (Duffield & Drinkwater,2008). It was also noted that the male batter spends approximately 136 minutes at the crease (Duffield & Drinkwater, 2008). Neither the breakdown for nor the duration of a century scored by a female batter has been defined and, as such, no specific scientific training protocols, similar to that developed by Houghton *et al.* (2011), have been created or implemented for female batters. This protocol, termed BATEX©, was developed using the motion analysis by Duffield and Drinkwater (2008), to reflect the typical physical demands of an ODI century in men's cricket. The protocol consists of six 21-minute stages, lasting 2h20 minutes (Houghton *et al*., 2011). During each stage, 30 balls (50 overs) are bowled to the batter using a bowling machine. Each stage is based on theoretical phases of play that occur during a batting innings. Each stage has different requirements in terms of effort and runs taken. Runs in each stage are predetermined from score card analysis from various international cricket matches and motion analysis by Duffield and Drinkwater (2008). The protocol is adaptable and effective for all forms of the game as each stage can be used independently of each other to perform research or to train batters as they are based on different phases of play. For example, one stage is a representation of a T20 match and can be utilised to determine the effects of that form of the game on batters.

There have been no motion analyses, century breakdowns or controlled studies on the demands of the game for female players

In the past few seasons, various records have been broken by female players, including the first double century in a test match by Elise Perry and the fastest century in a T20 match by Ashleigh Gardner in the Women's Big Bash League (WBBL) in December 2017 (CricInfo: Date accessed 25 January 2018). Female cricketers are beginning to break boundaries and subsequently deserve the same acknowledgment and recognition as their male counterparts.

1.2 Problem statement

A batting protocol that is specifically designed for female batters for research or training purposes has not yet been established. For effective batting training to be achieved, accurate and reliable data is a fundamental requirement. Therefore, the purpose of this study was to quantify the motion demands and utilise an ODI century and a T20 half-century run-breakdown analyses of women's cricket matches to establish a simulated batting protocol specifically designed for female batters.

1.3 Objectives of the study

The objectives of this study were to:

- Determine and quantify the motion demands of female batters during ODI and T20 cricket matches,
- Determine the breakdown of a century scored in ODI matches and the breakdown of a half-century scored by female batters in T20 matches, and
- Establish a simulated batting training protocol for female cricket players, using the above-mentioned objectives.

1.4 Organisation of research report

Chapter 1- Introduction indicating the lack of research in women's cricket and establishing the need for and importance of a simulated batting protocol.

Chapter 2- This chapter reviews the history of women's cricket in South Africa and the limited research on women's cricket around the world. The chapter also highlights the research on men's cricket thus emphasising the research gap.

Chapter 3- The methodology of the study is described in this chapter, including the population and game analysis. Ethical consideration is discussed in addition to the statistical analyses of the data.

Chapter 4- The description of the results, design of the protocol and statistical analyses are presented in Chapter 4.

Chapter 5- The findings of the study are detailed and explained and all efforts to relate them to existing literature are presented here. The limitations of the study are explained here to substantiate the limited results.

Chapter 6- The conclusion of the study is discussed here. Recommendations for future studies and research directions regarding the protocol are mentioned.

CHAPTER II

It must be noted that parts of this chapter have been included in the publication:

Munro, CE and Christie, CJ (2018). Research directions for the enhancement of women's cricket. *International Journal of Sports Science and Coaching*.

Review of literature

2.1 Introduction

The struggle for women to be acknowledged as having the ability to play competitive cricket began over 100 years ago (Odendaal, 2011; Williams, 1985). An example of this would be the initial use of a blue ball for ladies' cricket since the male organisers assumed that a red ball would be too unnerving for the female players (Odendaal, 2011). Once established that this was not the case, a white ball was created for use in both men's and women's ODI cricket (Odendaal, 2011). Furthermore, although Christine Willes was the first person to bowl overarm, her brother John took the credit for this (Odendaal, 2011). Examples such as these are widespread throughout the history of the sport. Noting that the first women's world cup was held in 1973 (two years before that of their male counterparts), that the first international women's T20 match was held in 2004 (one year before the first men's) and that the first ever day/night Ashes test was held on November 17, 2017 during the women's Ashes (a full month before the men followed suit), the lack of recognition for women's cricket has been a clear trend throughout the years. Furthermore, the first double century in limited-overs cricket was achieved by Belinda Clarke in 1997, whereas the first double century in men's cricket was only achieved in 2010 (Cricinfo: Date accessed 26 January 2018). This lack of acknowledgement and exposure has been attributed to a shortfall of media attention and the perception that cricket is a "man's sport" (Odendaal, 2011).

2.2 History of women's cricket in South Africa

Women first entered the cricket scene in 1808 in England but were restricted to the social aspect of the game. The wives of the players organised all social functions for the touring teams from England. The first recorded women's cricket club was the White Heather Cricket Club, formed in 1887 in England. A few years later in 1890, the club contracted two teams of female cricketers, known as ‘The Original English Lady Cricketers’ (Williams, 1985). Many of their male counterparts, however, disagreed with this concept, with some stating that cricket is a gentleman’s game and that these female players “might be original and English, but they are neither cricketers nor ladies” (McGirck, 1986). Many critics even went as far as to say that allowing women to play cricket would directly challenge the male dominance of the sport and undermine all of the values of manliness and Christianity upon which the ethos of cricket was based (Odendaal, 2011). The club was therefore closed after two years (Holt, 1989).

In South Africa, the first known report of women playing cricket is dated back to 1888 (Odendaal, 2011). In 1893, a proposal was put forward to the Western Province Cricket Club to allow women to become members. This was, however, rejected immediately. From the 1900s onwards, cricket was introduced into various girls’ schools; the most famous of these was Roedean in Johannesburg. This introduction into girls’ schools was spearheaded by Winifred Kingswell, who was known as the pioneer of women’s cricket in South Africa. She strongly believed in the value of sport for women. In 1921, Winifred formed the Peninsula Girls’ School Games Union and was elected as the first president in the same year (Odendaal, 2011).

The first international women’s cricket body was the Women’s Cricket Association, established in England in 1926. In 1934, the Cape Town-based Peninsula Ladies Cricket Club (PLCC) became affiliated with the Women’s Cricket Association in England. The PLCC had 30 members in 1934 and played against men (Odendaal, 2011). In 33 games over two seasons, they lost 21, won nine and drew three. By 1947, women’s cricket was able to start a league and select two Southern Transvaal teams to play against Rhodesia (now Zimbabwe) in Johannesburg. The Southern Transvaal Women’s Cricket Association was formed the following year and by 1952, it had grown to 10 clubs with 13 teams. Players in Cape Town re-established the Western Province Women’s Cricket Club (the old PLCC) in 1949 and in 1951, a new Western Province Women’s Cricket Union was formed. In 1952, the SA and Rhodesian Women’s Cricket Association (SARWCA) was established and was a “whites-only” association. This association was made up of seven Provinces: Border, Eastern Province, Natal, Northern Rhodesia, Northern Transvaal, Southern Transvaal and Western Province.

In 1956, the association created the SARWCA tournament in South Africa, in which an estimated 70 women from all the provinces participated (Odendaal, 2011).

An important milestone in women's cricket was the founding of the International Women's Cricket Club (IWCC). The idea of an International Women's Cricket body was first conceptualised in 1954. After an initial approach was made to interested countries namely, Australia, England, Holland, New Zealand and South Africa, the association created a special committee which drafted and compiled the initial constitution and rules in 1956. This was sent to the governing body and by 1958, a board was selected and the IWCC was established (Odendaal, 2011).

The IWCC paved the way for international competition and South Africa finally joined the small test circuit with England, Australia, New Zealand and Holland in 1958. During the 1960/1961 season, England toured SA, and Sheila Nefdt was appointed the first captain of the SA ladies side. During these test matches, Yvonne van Mentz scored the first ladies century (105 not out) for South African cricket. It should be noted that this team consisted exclusively of white players and it was only in 1981 that the first black female cricketer participated in the SARWCA cricket week (Odendaal, 2011). Even though South Africa was included in the test circuit, they were excluded from the first ever women's world cup in 1973 for undocumented reasons. Five South African players were meant to participate as part of the International XI, but the Caribbean team threatened to withdraw and therefore all South African players were excluded (Thompson, 2005).

The first known black women's cricket club was formed in Kimberly in 1909. This was a major milestone for the black community although they experienced many political and racial setbacks throughout the rest of the 20th century (Odendaal, 2011). It was only after democracy that there was a strong emphasis on black women's cricket development, however there continue to be many setbacks still facing these players. The South African Women's Cricket Association (SAWCA) was established in 1996, replacing the whites-only SARWCA. In 1997, the first national side since democracy was selected to tour Britain and Ireland. In the same year, the ladies' side reached the quarter-finals of the women's world cup held in India. In 2001, the South African side made the semi-finals of the world cup held in New Zealand and in 2005, South Africa hosted the world cup. This was a major milestone for women's cricket and in the same year, the first black female cricketer, Nolubabelo Ndzundzy from Border, was selected for the national side.

By the early 2000s, more than 9000 women from 1109 schools and 269 clubs were playing cricket in South Africa (Odendaal, 2011). In a major step towards standardising women's cricket, the ICC, and the IWCC decided in 2002 to merge. This finally took place in 2005, bringing male and female cricketers under one global coordinating body for the first time. In more recent years, the addition of the Australians Women's Big Bash League has increased media exposure of the game across the world. It has attracted a variety of international players (including South African players) and has improved Australian cricket dramatically.

2.3 Structure and laws of the game

The game of cricket began in the late 16th century. Having originated in southeast England, it became the country's national sport in the 18th century and has developed globally in the 19th and 20th centuries. International matches have been played since 1844, although international test cricket was only officially recognised in 1877 (Noorbhai & Noakes, 2015). The first laws of the game were put into practice in 1744 and these laws continue to form the basis of the laws being used today. These laws state that the game is played between two teams (of 11 players) on a field, which contains at its centre, a rectangular 22-yard-long pitch with a wicket at each end, which is the same length for both the men's and women's game. One team, designated the batting team, attempts to score as many runs as possible, while their opponents field. There are clear differences in women's cricket when compared to men's cricket. The weight of the ball for men's cricket can range from 155.9 g-163 g whereas the women's ball ranges from 140 g-151 g. Furthermore, the cricket field has smaller dimensions in women's cricket; the boundaries must be between 50.29 m and 64.01 m, in contrast to the 59.44 m to 82.30 m required in men's matches.

Women's test match cricket was the first form of the game and was played over three days, with three innings lasting two hours each; this has since changed to four days (Harris, 2005). It should be noted, however, that very few test matches are played in the women's league. Men's test matches, in contrast, are played over five days and are a frequent event. The innings are divided by a 40-minute lunch break and a 20-minute break for tea in the afternoon. The bowling team is required to bowl 90 overs per day dependent on the weather. The second form of the game is ODIs, which consist of two innings of 50 overs each with a 40-minute break between the two innings. T20 cricket was introduced as a third form and has had an enormous effect on the modern game (Noorbhai & Noakes, 2015). The match is 20 overs per side played in a maximum of 150 minutes between two teams. It is fast paced which is why this form of the game is thought to require higher levels of fitness when compared to test and ODI matches (Peterson *et al*., 2008). It is also said to be more entertaining which, in the case of the men's games, may be owing to the increased number of boundaries scored. The first women's T20 international match was held in August 2004 between England and New Zealand and was played six months before the first T20 match between two men's teams (Cricinfo: Date accessed 28 January 2018).

Certain aspects of the game, such as the number of players on the field at any one time, do not change regardless of the form of the game under consideration. Each team is composed of bowlers, batters, a wicket-keeper, and fielders. These roles are also the same irrespective of the format of the game being played. Although every player on the team is required to bat and field during the match, generally, each player possesses role-specific skills which contribute to the overall performance of the team during the match (Koley & Kashyap, 2010).

2.4 Bowling

There are various types of bowlers; fast, medium, off-spin and leg-spin to name a few. The styles of bowling differ in speed and technique. Each bowler, no matter the type of ball they bowl, will have a different bowling action, depending on their technique and training. There are three types of bowling actions; 1) side-on, 2) front-on and 3) a mixed action (Elliott, 2000). The different techniques are characterised by the body position adopted by the bowler (Elliott, 2000).

Depending on the bowling type, the bowling speeds and length of the run up to the wickets will differ. As fast bowlers require faster ball speeds, they will have a longer run up, whereas spin bowlers require much shorter run ups. It is speculated that as female fast bowlers bowl speeds of up to 120 km.h^{-1}, compared to the average 140 km.h^{-1} by male fast bowlers, their run up will subsequently be shorter than those of their male counterparts. A study by Savage & Portus (2002) found that the mean run up speed for female fast bowlers was 4.9 m.s^{-1}, which was similar to that of their male counterparts (Savage & Portus, 2002). The mean ball release speed of the female bowlers was 27 m.s^{-1} which was, however, much slower then what was reported for senior male fast bowlers, which in 1996 was 37 m.s^{-1} (Bartlett, Stockill, Elliott, & Burnett, 1996; Savage & Portus, 2002). These speeds may have increased or decreased over the years, but this is speculation as there is no recent research available.

During front-foot contact during the delivery stride, females have been found to have a mean peak vertical ground reaction force of 3.49 kN (±0.81) with a mean peak horizontal braking force of 2.13 kN (±0.52) (Stuelcken & Sinclair, 2009). The mean time to the peak vertical force was 0.033 s (±0.009) and the vertical loading rate was 121.31 kNs^{-1} (±73.78) (Stuelcken & Sinclair, 2009). This was found to be less than that of male fast bowlers (Hurrion, Dyson, & Hale, 2000; Portus, Mason, Elliott, Pfitzner, & Done, 2004). The authors stated that body mass had little effect on the magnitude of front-foot ground reaction forces in elite female fast bowlers (Stuelcken & Sinclair, 2009). It must be noted, however, that this was a pilot study and further work is required to determine the best method to minimise front-foot ground reaction forces.

2.5 Fielding

Fielders must concentrate for long periods of time. They are required to focus on every single ball that is delivered to the batter and there is always a chance that the ball will come to any fielder. Their role is to catch or stop any balls that come to them and return the ball quickly to the wicket. They are required to back up when another fielder is throwing the ball at the wickets as well as perform support with chases to the boundary. Depending on where the fielder is placed on the field, the requirements will differ. Field placement can be based on many different factors such as match situation, type of bowling, pitch conditions, the accuracy of bowling, and the batter's style and limitations. Fielding changes generally occur before an over is bowled, however, can occur between deliveries as well. The various fielding placements for men’s cricket are displayed in Appendix A. Whether these are the same for women's cricket is still unclear as the field is smaller and the strategic aspects of the game may be different.

2.6 Batting

One of the main components of cricket is batting i.e. the act or skill of hitting the cricket ball with a cricket bat to score runs or to prevent the loss of a wicket. The player who is currently batting is referred to as the batter and the shot or stroke is the act of hitting the ball. During a single innings, two batters from the same team bat. The batter facing the bowler is referred to as the striker while the batter at the bowler's end is referred to as the non-striker. Once a batter is dismissed or given out, they are replaced by another batter. This process continues until the end of the innings or until all batters are out, after which it is the other team's turn to bat.

The success of technical batting in the game of cricket generally depends on quick and precise footwork (Portus & Farrow, 2011). These technical skills must be completed under stressful time demands where the difference between a good and a poor bat-ball contact can be a matter of milliseconds (Abernethy, 1981; McLeod & Jenkins, 1991). One important factor is the initial reflexive movements of the batter's feet that occur just before the ball is released. These movements can take the form of three different motions: a backward movement, a forward movement, or a combination of the two. In addition, there are several different batting strokes, such as the cover drive and hook shot, which may be implemented by the batter depending on the type of bowling, the fielding placements or on the current situation of the match. With male international bowlers achieving ball speeds of 160 $km.h^{-1}$, batters have approximately 250 milliseconds to perceive the position of the ball and react appropriately to ensure the execution of the correct cricket stroke.

Researchers have demonstrated that batters utilise information from the bowler's action to anticipate the upcoming delivery which allows them to begin their movement preparation (Portus & Farrow, 2011). Furthermore, skilled batters have demonstrated superior information pickup relative to less-skilled (Abernethy & Russell, 1984; Müller & Abernethy, 2006; Renshaw & Fairweather, 2000) and younger or less-experienced players (Weissensteiner, Abernethy, Farrow, & Müller, 2008). The main understanding of cricket batting is derived from studies focusing on the visual-perceptual skills of cricket batters (Müller & Abernethy, 2006). Weissensteiner and colleagues (2008) found that skilled anticipation in cricket batting did not occur until the batter reached 18 years old, which they ascribed to two possible reasons. The first stated that the lowered temporal demands of the junior school cricket games, such as slower ball speed, were such that the batters had no need to rely on anticipatory processes to prepare their interceptive action as they had sufficient time to interpret and respond to the ball in flight (Weissensteiner *et al*., 2008). The second stated that the ability of younger players to detect subtle postural information from a bowler may require a significant accumulation of perceptual exposure to bowlers' movement patterns which is not acquired until late teenage years or until one has acquired more experience (Weissensteiner *et al.*, 2008).

Visual cues relating to the bowler's action, which may predict the intended ball trajectory, are analysed by the batters. Müller and Abernathy (2006) used projected video footage of the bowler's action. The authors examined the ability of skilled, intermediate-level, and less-skilled male cricket batters to utilise advance cues to anticipate the direction of swing and the length of the delivery. In the first trial, the video footage of the bowler was occluded in turn at back-foot landing, front-foot landing, and ball release. The authors found, at front-foot landing and ball release, that skilled batters were better at predicting the direction of swing than less-skilled batters. Skilled batters were also better at predicting the length of the delivery at ball release (Müller & Abernethy, 2006). In addition, skilled batters improved their prediction of the swing and length of the delivery when allowed to view up to front-foot landing, whereas less-skilled batters improved their prediction only when allowed to view up to ball release. These results indicate that skilled batters must have used advance cues from the bowler's action and that these cues were either not utilised or were incorrectly utilised by the less-skilled batters (Müller & Abernethy, 2006)

Taliep and colleagues (2007) studied the head position and movement of the centre of mass of skilled and less-skilled male batters when they played a shadow front-foot off-drive to video footage of a bowler delivering the ball. The authors hypothesised that the centre of mass of the head of the skilled batter was further forward than that of the less-skilled batter (Taliep, Galal, & Vaughan, 2007). This would thus contribute to the skilled batters' total body centre of mass being further forward, allowing them to lean better into the stroke. High-speed digital cameras were used to record the three-dimensional kinematics of 10 skilled and 10 less-skilled right-handed batters when playing a shadow front-foot off-drive to projected video footage. Skilled batters were more likely to identify the type of delivery bowled. Seventy percent of skilled batters had preparatory feet or foot movement before committing to play a forward stroke, while only 20% of the less-skilled batters used this trigger movement. Throughout the drive, the heads of the skilled batters were further forward of the centre base point than those of the less-skilled batters. This forward head position was linked with the tendency for the skilled batter's centre of mass to be further forward during the predicted bat–ball contact. There were no significant differences between groups in the shoulder angle, bat angle or bat speed during the different phases of the stroke (Taliep *et al*., 2007). There was, however, an inclination for the less-skilled batters to have a larger hip angle at contact. The most important finding of this study was that throughout the front-foot stroke, as with the drive, the head of the skilled batter was further forward of the centre base point than that of the less-skilled batter. Coaches should, therefore, emphasise to less-skilled batters the importance of leaning with the head into the stroke. This study provides further evidence for the importance of a trigger movement before ball release, a strategy used by skilled batters, most probably to get into a rhythm to enable them to time to perfection the contact of the bat with the ball (Taliep *et al.*, 2007). Whether this strategy would be effective for female batters is unknown.

During the early years of cricket (1895-1954), batters hit the ball more frequently with fewer dot balls, whereas today, batters tend to leave more balls during test cricket (Noorbhai & Noakes, 2015). Whether this is true for female batters is still unknown as there are no documented studies to date.

2.7 Physical characteristics of cricketers

While some sports have been studied extensively, the morphological and anthropometrical characteristics of cricketers, or more specifically batters, have been under-researched (Stretch, Bartlett, & Davids, 2000). Anthropometrically, male batters tend to be shorter and lighter than the other players, but generally have a larger relative fat mass, whereas male bowlers have been shown to have a greater absolute muscle and bone mass compared to batters (Stretch *et al*., 2000). Gore (2000) investigated the anthropometric characteristics of Australian cricketers and he indicated that bowlers were, on average, at least 200 mm taller than batters (Gore, 2000). This may be owing to the fact that for batting, size may not be advantageous, whereas it is preferred that bowlers are tall (Stretch *et al*., 2000). According to Stretch (2000), who assessed the morphological characteristics of both batters and bowlers, most male cricketers have a tall athletic build; however, there are distinct physical differences between batters and bowlers (Stretch *et al*., 2000). There are various physical characteristics of cricketers that have been commonly reported in many studies (Houghton *et al*., 2011). Body fat percentage was found to range between 9.3% and 20.1% amongst cricketers (Christie, Todd, & King, 2008; Noakes & Durandt, 2000; Stretch *et al*., 2000)

In terms of female cricketers, there is very limited research. There have, however, been two studies that have investigated the anthropometrical and morphological characteristics of female cricketers. Stuelcken and colleagues (2007) evaluated 26 females and 26 male elite Australian fast bowlers by measuring body fat percentage, lengths, breadths, girths, mass, and height. The Bivariate Overlap Zone (BOZ) for height and mass was calculated using the tool described by Norton & Olds (2001) which assesses the differences in the "selection pressures" between males and females within a given sport (Norton & Olds, 2001). It was found that female bowlers were best described as mesomorph-endomorphs and male bowlers as balanced mesomorphs. It was found that males differed from females in absolute measures, proportionality, and somatype and that females had a greater amount of subcutaneous fat (Stuelcken *et al*., 2007). The authors stated that females have a greater amount of adipose tissue but less skeletal muscle. This functional combination will decrease the ability of female bowlers to accelerate their limbs. This may explain why the mean approach velocity of female fast bowlers was 15% slower than their male counterparts. Stuelcken *et al.* (2007) stated that most fast bowlers are taller compared to other players, which is advantageous as it increases the angle of release, which allows for the extraction of a greater bounce off the pitch. Koley & Kashyap (2010) studied Indian inter-varsity female cricket players and found significantly higher measures of subscapular skinfold, suprailiac skinfold, calf skinfold and thigh circumference measures in cricketers when compared to a non-cricket playing control group (Koley

& Kashyap, 2010). This study was, however, limited as the authors pooled their data and did not separate players according to their role on the field. The study did not state what somatotype the players were or the total body fat percentage. The data were not compared to male data or to the study by Stuelcken *et al.* (2007). Evidently, more research is needed on the physical characteristics of female cricketers.

2.8 Injuries in cricket

There are several ways in which an injury can be defined in the context of cricket (Pote & Christie, 2013; Stretch, 2003). However, a consensus document was released in 2016 by Orchard and Colleagues which states that an injury is defined as an incident that either prevents a player from being fully available for selection for a major match, or during a major match, causes a player to be unable to bat, bowl or keep wicket when required by either the rules or the team's captain (Orchard *et al*., 2016). Injury prevalence and risk for male cricket players have been readily researched in comparison to women's cricket. There have been various studies that have focused on all players, not just fast bowlers as has been the case for women's cricket, and have quantified injury prevalence over several seasons (Finch, White, Dennis, Twomey, & Hayen, 2010; Johnson, Ferreira, & Hush, 2012; Walker, Carr, Chalmers, & Wilson, 2010).

Injuries are common in Australian female cricketers (109 out of 164 sustained an injury in the 2014/2015 season) with the distribution reported being: 30.4% muscle injuries; 27.8% joint or ligament injuries and 21.7% gradual onset/overuse injuries (Perera *et al.*, 2017). The most frequently injured areas were the distal lower limb (24%, n=26) and head, neck, and spine (5%, n=5). The majority (43%) reported receiving treatment from a physiotherapist; 29.2% used self-treatment and 12.5% did not seek any treatment (Perera *et al.,* 2017). Compared to previous studies of females in sports, the current study reports a higher frequency of injury (Kelly, McLaughlin, & Ross, 2003). In contrast to previous Australian studies on elite female fast bowlers which focused on shoulder and back pain (Stuelcken, Ferdinands, Ginn, & Sinclair, 2010; Stuelcken, Ferdinands, & Sinclair, 2010; Stuelcken, Ginn, & Sinclair, 2008a; Stuelcken *et al*., 2008b; Kelly *et al*., 2003), the most commonly injured anatomical location in the survey by Perera *et al.* (2017) was the distal lower limb.

The study by Perera and colleagues (2017) showed similar results to studies that investigated injury risk for male cricketers. It was found that a total of 1606 injuries occurred, between 1998 and 2004, in 783 cricketers (Stretch, 2007). Most of the injuries were classified as acute injuries (65%), with chronic and acute-on-chronic injuries accounting for 23% and 12% of all injuries, respectively (Stretch & Raffan, 2011). Bowling resulted in 40% of all injuries with 55% of these being lower limb injuries (Stretch & Raffan, 2011). This was further substantiated by Stretch, Raffan, and Allan (2009), who carried out an injury surveillance of four provincial teams in South Africa over the seasons between 2004 and 2006 by means of a questionnaire. Stretch *et al.* (2009) found that 180 injuries were sustained over the two seasons, with bowling accounting for the highest percentage (29%), followed by fielding and wicket-keeping (27%), and then batting (19%) (Stretch, Raffan, & Allan, 2009). Throughout both seasons, the lower limbs accumulated the highest percentages of injuries with an average of 42% of all injuries being to the lower limb, significantly higher than other presenting areas. During the two-season period, haematomas (14%), muscle strains (16%), traumas (17%), tendinopathy (11%) and acute sprains (11%) were the major injuries with other injuries unspecified accounting for 33% (Stretch *et al*., 2009). These results from Stretch *et al*. (2009) imply that the most common injuries likely to be sustained are lower limb injuries, which corresponds with the results suggested by Perera and colleagues (2017) on injury prevalence in female cricketers.

In coherence with the findings of Stretch *et al*. (2009) and Stretch (2007), indicating that the lower limb area is the most affected by injury, it has further been found that, more specifically, hamstring and thigh strains have the highest incidence rate (Orchard, James, Kountouris, & Portus, 2010; Ranson, Hurley, Rugless, Mansingh, & Cole, 2013). Orchard and colleagues (2010) believe that the increase of Twenty-20 cricket and the higher intensity over shorter periods of the game could be responsible for this. In addition, Orchard *et al.* (2010) found that the increase in Twenty-20 cricket in the recent years, increasing the overall workload for the season, has caused an excessive increase in injury prevalence in pace bowlers. Whether this has the same effect on female bowlers is still unknown.

As there is no research on batting-specific injuries in women’s cricket, the focus will only be on the available research on female fast bowlers. Shoulder injuries are common in female elite fast bowlers (Stuelcken *et al.*, 2008b). Stuelcken and colleagues (2008) compared the shoulder strength and range of motion of elite female cricket fast bowlers with and without a history of shoulder pain. The authors found that 12 out of 26 elite fast bowlers had a history of shoulder pain and that eight of these had experienced at least one episode of shoulder pain in the previous 12 months. Isokinetic strength and active range of motion were assessed in both the bowling and non-bowling shoulders of all 26 players. The external rotation range of motion was significantly greater in the bowling shoulder when compared to the non-bowling shoulder for the group with no history of pain (Stuelcken *et al.*, 2008b). The internal rotation range of motion was significantly less in the bowling shoulder for the total cohort and those with a history of shoulder pain (Stuelcken *et al*., 2008b). There were no differences in any of the isokinetic measures in the bowling shoulder between bowlers who either did or didn't have a history of shoulder pain. Stuelcken *et al.* (2010) investigated shoulder distraction force in cricket fast bowling. The authors wanted to determine if bowling action produces high shoulder distraction forces and whether this could be a potential mechanism for the development of shoulder pain in female fast bowlers. Eighteen female fast bowlers, 13 right-handed and five left-handed bowlers were assessed. They found that there was a large shoulder distraction force (599N ± 111) at the joint during the early stages of the follow through of the bowling action (27º ± 15 past the vertical). Once these values were normalised by body weight, it was found that the values were similar to those of male and female baseball pitchers. These findings suggest that shoulder distraction force should be considered as a contributing factor in the development of shoulder pain in female fast bowlers. The repetition of the distraction forces in this study may be sufficient to cause an overload on the rotator cuff, which is suggested to be the main mechanism to resist these forces (Stuelcken *et al*., 2010).

It is well established that low back pain (LBP) is a common problem amongst male fast bowlers (Crewe, Elliott, Couanis, Campbell, & Alderson, 2012; Hardcastle, 1993; Johnson *et al*., 2012; Kountouris, Portus, & Cook, 2012), whereas females have a lower career history of LBP (Stuelcken *et al*., 2008a). Stuelcken *et al.* (2008), therefore, investigated the musculoskeletal profile of the lumbar spine and hip regions in elite cricket fast bowlers. The authors assessed 26 female elite fast bowlers and found that 14 (54%) of the females tested had a history of LBP, which is lower than male fast bowlers in South Africa (76%) (Harris, 1993) and Australia (66%) *(*Portus *et* *al.*, 2004). It is difficult to compare these results, however, as a comparison may be misleading owing to females playing less frequently than males during that period. The decreased work load may allow more time for rest and recovery which could potentially avert the development of more serious injuries. It has, however, been stated that a reduced load followed by reloading may actually increase injury risk (Gabbett, 2004). Female fast bowlers may, therefore, be at a higher risk although this has not been quantified and is an area that requires further investigation. Female fast bowlers showed significantly more bilateral hip extension compared to the males. The female participants that had a history of LBP showed significantly reduced lumbar lateral flexion range of motion to the bowling arm side (Stuelcken, Ginn, & Sinclair, 2008a).

Female fast bowlers are just as likely to use a mixed action (19 of the 26 tested) as their male counterparts. Bowlers who used mixed action are suggested to be no more likely to have a history of LBP and that the lateral flexion of the thorax relative to the pelvis was the key variable that distinguished between bowlers with and without a history of LBP (Stuelcken, Ferdinands, & Sinclair, 2010).

2.9 Movement patterns of cricket

Time-motion analysis has been implemented for over 30 years (Holmes, 2011). Many of the aims of this type of research have been to increase the knowledge and understanding of the physiological demands of the specific sport to assist with the development of training programs (McLean, 1992). In terms of cricket research, time-motion analysis is the first stage in developing cricket-specific training protocols (Duffield & Drinkwater, 2008). Findings from these studies should be used to validate the movement patterns of an exercise protocol that simulates the physical demands of batting in cricket. Time-motion analysis in cricket batting emerged in the mid to late 20th century (Noakes & Durandt, 2000). In recent years, there have been several motion-analysis studies on male cricket games (Duffield & Drinkwater, 2011; Houghton *et al*., 2011; Petersen *et al*., 2009; Rudkin & Donoghue, 2008). These studies observed movement patterns during batting, bowling, and fielding.

Petersen *et al.* (2009) observed T20, ODI and test cricket matches of academy players using GPS (global positioning system) to monitor movement. The mean distance covered per hour by players in each position and format of the game can be seen in Figure 1. Fast bowlers covered the most distance across all formats. The work-to-recovery ratio was determined by looking at total time standing, jogging, running, striding and sprinting throughout the game. In terms of the batters, the work-to-recovery ratio for ODI games was found to be (1:50), covering on average 2.6 $km.h^{-1}$ during the ODI and T20 formats while at the crease (Petersen *et al*., 2009).

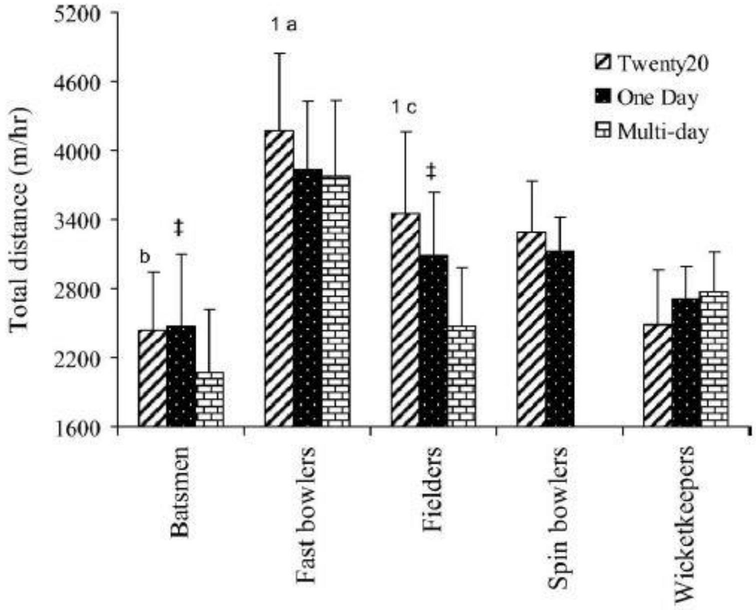

Figure 1: Total distance covered per hour by position in different formats of cricket. Taken from Petersen *et al.* (2009)

The first study to analyse time motion of elite cricket batting was by Duffield & Drinkwater (2011). The authors quantified the movement patterns and changes in the activity of batters who have scored a test or an ODI century. Data were collected from 13 test centuries and 12 ODI scores above 80. Time-motion analysis was conducted when the players first appeared in the footage until they scored 100 runs or were dismissed above 80 runs in an ODI match. The authors recorded seven different motion categories, being standing, walking, jogging, striding, sprinting, the playing a shot and lateral motion. Along with these categories, the authors completed basic statistics on the number of balls faced to reach 50 and 100 runs, the duration of each innings, the total number of balls faced, and the number of shots played.

The frequency and duration of repeated-sprint activity were assessed by determining the duration of “high-intensity” (sprinting and striding) and the duration of recovery or “low-intensity” (standing, walking and jogging). It was found that most of the time spent at the crease consisted of walking and standing and that spurts of “high-intensity” lasted around 1.5 seconds(s) and that a change in the mode of movement occurs every 8 s. The amount of sprinting and striding in a test century (1.1min s=0.3) is comparable to that in Super 12 rugby (0.5-2 min) and field hockey (0.5 mins). While there are similarities, the duration of a test century (213.4 mins, s=31.9 min) is much longer than an 80-minute game of rugby or soccer. A test century involves over two hours of standing, one hour of walking, five minutes of jogging and several minutes of high-intensity exercise in short intervals (Duffield & Drinkwater, 2008). This may be considered to be a substantial physiological load and the likelihood of fatigue increases (Duffield & Drinkwater, 2008). This has resulted in a ratio of 1 s of high intensity for every 67 s of low-intensity activity. When compared to test centuries, ODI centuries are shorter, fewer balls are faced and there are fewer and shorter periods of low-intensity activities. This results in fewer recovery periods. Owing to the ODI matches being shorter, the decreased number of recovery periods results in an increase in the acute physiological demands placed on the batter. In terms of time, batters will spend one-hour standing, 45 minutes walking, five minutes jogging and three minutes engaged in high-intensity activities. This results in a ratio of 1 s of high intensity to 47 s of low-intensity activity. Petersen and colleagues (2009) quantified the time-motion characteristics of five cricket positions (batters, fast bowlers, fielders, spin bowlers, wicketkeepers) in T20 men’s matches. The authors stated that T20 male cricketers covered between 6.4 - 8.5 km, with 0.1 – 0.7 km of this distance spent sprinting. Fast bowlers covered 8.5 km and sprinted 42 times. Wicketkeepers covered 6.4 km and sprinted 5 times. While batting, for 30 minutes, players covered ~ 2.5 km and sprinted 12 times. The authors, therefore, concluded that male fast bowlers and fielders have substantially greater physical demands than spin bowlers and wicketkeepers in T20 cricket (Petersen *et al*., 2009).

These observations can be used to improve training practices, improve batting performance and reduce the possible impact of fatigue during cricket centuries (Duffield & Drinkwater, 2008). Houghton *et al.* (2011) developed a simulated cricket batting innings (Table 1) for testing and training using the motion analysis by Duffield and Drinkwater (2008). The simulation was developed to reflect the typical physical demands of an ODI century in men’s cricket. The protocol consists of six 21-minute stages, lasting 2 h 20 minutes (Houghton *et al*., 2011). During each stage, 30 balls (50 overs) are bowled to the batter using a bowling machine. Each stage is based on theoretical phases of play that occur during a batting innings. Each stage has different requirements in terms of effort and runs taken. Runs in each stage are predetermined from score-card analysis from various international cricket matches (Houghton *et al*., 2011). This protocol has been used in other studies to determine the demands of prolonged, high-intensity cricket batting (Houghton *et al*., 2011; Pote, 2013). To the author’s knowledge, there are no studies that have focused on the motion demands of female cricket.

Table 1: The running-between-the-wickets demands required each over during the simulated batting innings (BATEX) (Taken from Houghton, 2011)

	Runs completed in each over of BATEX				
BATEX stage and description	Over 1	Over 2	Over 3	Over 4	Over 5
1. Building momentum	1,1	No runs	1,1,2	1,4	1,4
2. Taking initiative	1,1	1,1,2	1,1,4	1,1,2	1,1,4
3. Fighting back	No runs	1	1,4	2,3	1,4
4. Power play	1,1,4	1,1,2	1,1,4	1,1,2,3	1,1,4
5. Maintaining tempo	1,3	1,1,2	1,1,4	1,1,2	1,1,4
6. Closing out the game/innings	1,1,3,4	1,1,2,4	1,1,4,1	1,1,2	1,1,2,4

2.10 Physiological and perceptual requirements of cricket

It has been suggested that the demands placed on cricket players vary for each position, with fast bowlers having the greatest workload (Petersen, Pyne, Dawson, Portus, & Kellett, 2010). Many studies on cricket in general, however, have only investigated the injuries that occur during batting and very few studies have looked at the physiological demands of cricket or the physiological, biomechanical and anthropometric attributes of professional cricketers (Noakes & Durandt, 2000). One of the first studies to examine the estimated energy cost for a cricket player during a five-day test match was Fletcher (1955). Fletcher showed that the average energy expended during a five-day test match was 86.4 $kcal.m^2.h^{-1}$ (Fletcher, 1955), which suggested that cricket was a physically unchallenging sport (Christie, 2008). Fletcher's study was, however, flawed as the measures he utilised were not accurate enough to properly determine the energy expended during the match as he included time spent sitting when not out in the field. Since that initial study, cricket has evolved into various forms, from the five-day test match to ODIs and finally to the most recent T20 format. Each format has varying physiological, psychological and perceptual demands (Pote & Christie, 2016).

For example, Noakes and Durandt (2000) estimated the peak activity of a batsman during an ODI, and from this estimation, it was deduced that the physiological demands of batting during an ODI are more substantial than originally thought. It was also found that South African international batters had a higher predicted VO_{2max} than bowlers, based on a 20 m shuttle run (Bartlett, 2003). It was therefore concluded that the idea of cricket being a physically unchallenging sport is inaccurate for international batters (Bartlett, 2003). In terms of the most recent form of match play, being T20 matches, there is no research on females and all the studies have been done on male cricketers only. Petersen and colleagues (2010) found that players' heart rates ranged from 149 to 167 $bt.min^{-1}$ for T20 matches (Petersen *et al.,* 2010). When compared to ODIs, Nicholson and colleagues found that players had a heart rate between 139 and 154 $bt.min^{-1}$ (Nicholson, Cook, & O' Hara, 2009). These studies indicate the varying physiological demands that can be placed on cricketers, emphasising the need for gender- and match-specific research.

Vickery *et al*. (2013) investigated the reliability of the Battlezone© and the physiological demands placed on cricket players during the protocol. This protocol is a small-sided cricket game played to simulate the gameplay within the inner circle of the middle section of an ODI cricket match. The authors found that across all playing positions, being batter, bowler, fielder and wicket keeper, most of the time was spent between 51-85 % HR_{max}, whilst blood lactate concentration and ratings of perceived exertion for both batters and bowlers ranged from 1.1-2.0 $mmol.L^{-1}$ and 4.2-6.0 on the 10-point Lickert scale, respectively. Furthermore, the total distance traveled ranged from 450-1189 m, with mean speeds ranging between 24-66 $m.min^{-1}$. The authors concluded that based on the physiological responses reported, Battlezone© may have a conditioning effect for cricket players (Vickery, Dascombe, Duffield, Kellett, & Portus, 2013). Knowing the physiological demands placed on players during practice and match scenarios is vital in preventing injuries and understanding the workloads placed on the players and thus to train them accordingly. The need for a similar protocol for women's cricket is constantly increasing as the number of matches played is increasing substantially every year.

2.10.1 Physiological requirements of batting

King and colleagues (2002) focused mainly on thermoregulation and the effect of protective gear worn by batters on physiological, perceptual and performance responses. The work-bout was based on observations of matches played at the 1999 cricket world cup as well as from specific high-scoring ODI innings played between 1991 and 2001 (King, Christie, & Todd, 2002). A game was considered high-scoring when more than 260 runs were scored in one innings. Players were required to bat facing deliveries that were bowled, receiving one delivery every 30 seconds for a total of seven overs (42 balls). After every third delivery, the batter was required to complete a full shuttle run at a full pace between two creases which were set at the same length of a cricket pitch. The two by two singles run per over, which made up 28 runs in all, simulated the high work rate that was most likely to be achieved after the 15th over in a high-scoring one-day international (King *et al.*, 2002). Thirty-second periods of no activity were also allowed between deliveries to simulate the time taken for the bowler to walk back to his mark, and the one-minute break between each over was reflective of a change in bowling. Although the focus of the study was on thermoregulation, heart rate responses were recorded during the seven-over simulated work-bout and it was found that the heart rate reached an average of 136 (±13.00) bt.min^{-1}. It was also found that heart rate in the final over of the protocol was significantly higher 151 (±11.00 bt.min^{-1}) when batters performed the protocol in high temperatures (23.80±2.20 ^{o}C) wearing full cricket kit, than when the protocol was performed in low temperatures (13.30±1.90 ^{o}C) without wearing full cricket kit (145±11.00 bt.min^{-1}). This suggests that the protective gear worn in cricket in combination with the environmental conditions has an impact on a batsman's physiological responses (King *et al*., 2002). Furthermore, Christie *et al*. (2008) looked at selected physiological responses during batting in a simulated cricket work-bout and utilised the same work-bout as King *et al.,* (2002). The physiological responses that were assessed included heart rate, breathing frequency, tidal volume, ventilation, oxygen uptake and metabolic carbon dioxide production. It was found that all the physiological responses increased significantly from the first to the second over and then stabilised. This excluded heart rate which continued to increase significantly until the end of the third over, after which it stabilised. According to Christie *et al.* (2008), this was owing to factors such as emotional state and food intake. From this study, the mean heart rate of the batters was 145 (±10.80) $bt.min^{-1}$ while VO_2 reached a mean value of 26.70 (±1.40) $ml.kg^{-1}.min^{-1}$. This was a pilot study with a limited sample size which suggests that there is a need for further research into the physiological demands of batting.

These studies all showed that the physiological demands placed on male batters are much higher than originally thought. The problem though is that these studies used short-duration, high-intensity work-bouts, and responses were not observed over longer time periods.

Noakes & Durandt (2000) estimated that during an ODI, a hypothetical batting player, who scored 100 runs, would cover a distance of 3.2 km during eight minutes of activity, and the batter would bat for at least two hours to achieve that score. This was, however, an estimated value but was greater than that initially recorded by Fletcher (1955). A more accurate representation of the physiological demands of scoring a century was performed by Houghton (2011), who created and implemented the use of the BATEX© protocol to determine the physiological demands of scoring an ODI century. This study looked at responses over an extended period of time instead of the short-duration, high-intensity work-bouts previously used. The author found that mean heart rate was 130±16 $bt.min^{-1}$ and tympanic temperature remained constant. It was stated that the physiological strain placed on the batters was moderate. A limitation of this study was that the physiological measures were delimited to heart-rate responses, tympanic temperature, and sweat rate. This study was replicated by Pote and Christie (2016) who studied the effect of the BATEX© protocol on university batters. It was found that most physiological responses increased and decreased accordingly with the low- and high-intensity stages apart from the respiratory exchange ratio and core temperature responses. Ratings of Perceived Exertion (RPE) increased and sprint times got slower as the protocol progressed. The authors concluded that the simulated batting protocol significantly impacted the physiological and perceptual responses of the batters over time (Pote & Christie, 2016).

2.10.2 Perceptual demands of cricket

Ratings of perceived exertion are subjective perceptions of effort during exercise and have been linked to physiological responses. However, RPE during men's cricket activity has been under-researched, especially with respect to batting for extended periods (Christie & Pote, 2014).

A study performed by King *et al.* (2002) stated that when using a seven-over, high-intensity spell, the batters showed an increase in RPE over time from a mean of '10' at the start of the protocol (over one) to a mean of 15 at the end of the work-bout (King *et al*., 2002). The King *et al.* (2002) study was a short-duration, high-intensity protocol whereas a study by Houghton *et al.* (2011) investigated RPE over extended periods of time. Houghton *et al.* (2011) measured the RPE of batters batting during the BATEX© protocol. A mean RPE of 13 was recorded and responses increased and decreased with the high- and low-intensity stages, respectively. Stage one showed the lowest (10) and stage six the highest (16) responses. A similar study by Pote and Christie (2016), who utilised the BATEX© protocol, indicated that RPE ranged from 8 during stage one and increased to 16 by the end of the protocol. These studies show an interesting contrast to the short, high- intensity studies, as it suggests that RPE increases as a function of exercise duration rather than intensity (Pote & Christie, 2016). To the author's knowledge, there have been no studies on the perceptual responses of female batters in training or match scenarios.

2.11 Conclusion

While research is sparse in the field of cricket science more broadly, research on female cricketers is very limited. The female literature has also focused predominantly on elite fast bowlers in Australia. Previous research has focused on injury prevalence and physical and biomechanical characteristics. It is evident that more research is required on female cricketers of all playing positions from all regions of the world where cricket is played and on players of all levels. Furthermore, previous literature has not examined the demands of the different formats of the game as no research has investigated real-time play (or even simulated play).

CHAPTER III

Methodology

3.1 Introduction

For effective batting training to be achieved, accurate and reliable performance and movement data is a fundamental requirement. These data are not available for women's cricket and have been substituted with subjective assessments by coaching staff. Performance analysis, such as time-motion studies of the game, can assist to provide this information in a more accurate and reliable manner. One of the most commonly reported uses of this information is to identify physiological demands of the game to provide a more detailed understanding of the game for the specificity of training regimes and protocols.

3.2 Design of study

This study was an observational time-motion analyses of women's T20 and ODI cricket matches, which analysed the batting and bowling innings of 10 international matches taking place between 2012 and 2017. This was done in order to describe the movement demands of women' cricket. The database, CricInfo, was then utilised to describe the demands of scoring an ODI century and a T20 half-century in women's cricket. The breakdown of South Africa's century demands was performed in order to determine if specific training is needed to improve the team's performance.

3.3 Matches analysed

Time-motion analyses of one-day international and T20 innings were conducted on international cricket matches played all over the world between 2012 and 2017. Observations of recordings were from the public domain (with permission from the governing body, Cricket South Africa) and the licensed broadcaster (SuperSport) and as such, no ethics approval was needed. The following countries were included in the time-motion analyses: South Africa, Australia, England, New Zealand, Sri Lanka and the West Indies as these were the countries playing in the available televised matches. Four ODI and six T20 innings were used for the time-motion analyses due to the limited availability of televised matches, this lack of televised matches severely restricted the sample size. The ODI innings that met the criterion of 100 runs scored and the T20 innings scores above 50 runs were utilised in the run breakdown, which included scores from the top 10 countries ranked by the ICC.

3.4 Match analysis

Each match (innings) was viewed, and the times of each variable were recorded using a stopwatch; time was measured in minutes and seconds. There are more advanced methods for observing time-motion, such as GPS and image recognition, however many of these techniques are expensive and inaccessible (Holmes, 2011) and thus were not used.

3.5 Motion categories

The game analyses were divided into the bowling and batting innings.

3.5.1 Bowling innings

For both the ODI and T20 matches the following variables were recorded:

- Duration of the innings - the time from the first ball until the end of the batting or bowling innings.
- The time between deliveries – which was recorded from the moment the ball was released from the bowlers hand up until the bowler returns to her mark.
- Time for a completed over - the time it took for the bowler to complete her six-ball over.
- Time between overs
- Time for changing of the bowler between overs

These variables were chosen in order to determine the mean time the batters are required to focus and prepare for each delivery or over.

3.5.2 Batting innings

The variables recorded, with regards to batting, were different for the ODI match and the T20 matches. For the ODI match the following variables were recorded:

- Duration of the innings and for both power-plays
- Duration and the number of runs scored
- Duration of the drinks break.

The innings was then broken up into:

- Number of runs

- Number of wickets
- Duration for the first 25 overs and the last 25 overs

For the T20 matches, it was similar; however, only one power play took place (overs 0-6) and the innings was then broken up into the first 10 overs and the last 10 overs.

3.6 ODI century and T20 half-century analyses

As centuries were not scored in the televised matches that were available, Cricinfo (http://www.espncricinfo.com) was accessed to determine the breakdown of scoring a century. All centuries and half centuries scored from 2008 to 2017 from the following countries were used: South Africa, England, New Zealand, Australia, the West Indies, India, Sri Lanka and Pakistan. The runs scored in each century were broken up into the number of singles, twos, threes, fours, and sixes scored. These values were used in conjunction with the time-motion analyses to determine the physiological and overall workload that is placed on female batters during these matches.

3.7 Data handling and analysis

All data was transferred to Microsoft Excel where the data was analysed. Not all variables were statistically comparable, and therefore, only descriptive statistics were used for the motion analyses of the ODI and T20 batting innings. All other variables were statistically analysed. These statistics were used to allow comparisons between samples of the formats and countries analysed for both the motion and the ODI century and T20 half-century demands recorded.

3.8 Statistical analyses

All statistical analyses were performed using R version 3.3.1 (2016-06-21). The level of significance was set at $p<0.05$, meaning a confidence interval of 95%. Descriptive measures of the motion analyses and run breakdown of both the ODI and T20 match data included mean values and standard deviations. All motion categories were recorded in time as minutes and seconds. A one-way ANOVA was used to compare differences between various measures in the time-motion analyses of the ODI and T20 innings and a century and T20 run breakdown. Posthoc analyses (Tukey's) were used to identify specific areas of differences between the formats or between countries.

3.9 Protocol design (W-BATEX)

Using the data obtained in the time-motion analyses and century breakdown, a century protocol was designed. The design of the simulated batting protocol for female batters replicates the method designed by Houghton *et al.* (2011) who developed the BATEX© protocol for male cricketers. The simulated batting innings will be composed of four stages that will last the total duration of a typical women's century. Each stage of the simulation will be based upon theoretical phases of play that may occur during a batting innings, being building momentum, power play, maintaining tempo and closing out of the innings. The "fighting back" stage from the Houghton *et al.* (2011) protocol was removed as it was based on test match data, which were not analysed in this study.

To create the protocol, the following variables will be utilised:

- Time taken to score a century (obtained from Cricinfo).
- Number of deliveries faced to complete an ODI century (obtained from Cricinfo).
- Number of dot balls to account for no runs scored in an over (obtained from Cricinfo). .
- Time between deliveries and time for a complete over (obtained from televised matches).
- Number of ones, twos, threes, fours and sixes and the percentage of each scored per over (obtained from Cricinfo).
- The percentage of boundaries and non-boundaries scored (obtained from Cricinfo).

3.10 Summary of methods

Time-motion analyses of one-day international and T20 innings were conducted on international cricket matches. The innings were divided into the bowling and batting innings. The ODI innings that met the criteria of 100 runs scored and scores above 50 runs in the T20 innings, taken from the CricInfo database, were utilised in the run breakdown, which included scores from the top 10 countries ranked by the ICC. All variables, except the motion analyses of the ODI and T20 batting innings, was statistically analysed. The time-motion analyses and century breakdown were utilised in the establishment of a simulated batting protocol.

CHAPTER IV

Results

The results presented are descriptive in nature for the time motion analyses followed by the run breakdown. Owing to the limited sample size and lack of data in the motion analysis, only the bowling innings of the ODI and T20 motion analyses were statistically compared. The century and T20 half-century breakdown were statistically compared between countries and across years. The year range was changed to 2012-2017 for the statisical analysis of the T20 half-century, since from 2009 to 2011 there were only two samples for each year and this could not be statistically analysed.

4.1 Time-motion analysis

4.1.1 ODI bowling innings

The motion demands of four ODI matches were analysed and separated into the bowling and batting innings. The ODI bowling innings consisted of 50 overs. Table 1, represents the measures and mean values for each innings and indicates that the duration of the ODI bowling innings, was 169±39.65 minutes. There were 24.86±4.30 seconds between deliveries and 0.55±0.08 minutes between overs. An over (six deliveries) took 2.45±0.27 minutes. When the bowling side changed to a new bowler, it took 1.12±0.13 minutes.

Table 2: Mean and SD of the ODI bowling innings taken from the motion analyses of four matches (eight innings)

	Duration of Innings (mins)	Time Between Deliveries (s)	Time for Complete Over (min)	Time for Change of Over (min)	Time for Change of Bowler (min)
	194.03	18.15	2.36	0.56	1.20
	174.31	22.36	2.29	1.07	1.20
	181.30	32.95	3.08	0.53	0.47
	201.47	26.19	2.37	0.45	1.18
	78.28	26.21	2.35	0.48	1.05
	151.23	22.58	2.25	0.58	1.21
	190.13	26.55	2.52	1.01	0.59
	181.25	23.85	2.38	0.48	1.22
MEAN(SD)	**169±39.65**	**24.86±4.30**	**2.45±0.27**	**0.55±0.08**	**1.12±0.13**

(s) refers to seconds; (SD) =standard deviation; (min) =minutes

4.1.2 ODI batting innings

The ODI batting innings consisted of 50 overs (Table 2). The mean score during the first power play (overs 0-10.1) was 41±9.74 runs with 1.38±1.06 wickets being taken. The mean score during the second power play (overs 36-40), known as the batting power play, was 28±19.55 runs with 0.714±0.755 wickets lost. The mean duration of the first and second power play was 39.19±4.134 and 18.7±1.68 minutes respectively. Each innings had two scheduled drinks breaks lasting 3.19±0.28 minutes.

Table 3: Mean and SD of the ODI batting innings taken from the motion analyses of four matches (eight innings)

Batting Team	Duration of Innings (min)	Power Play				Duration of Drinks Break
		Overs	Number of runs	Number of wickets	Duration (min)	
West Indies	194.03	0-10.1	39	2	42.33	3.17
		36-40(B)	11	1	19.08	3.50
New Zealand	174.31	0-10.1	47	3	45.58	3.28
		36-40(B)	23	1	16.24	3.41
England	201.47	0-10.1	54	0	41.40	3.14
		36-40(B)	67	0	20.48	3.21
South Africa	181.30	0-10.1	35	0	34.18	3.11
		36-40(B)	40	1	19.27	3.01
South Africa	78.28	0-10.1	38	2	33.40	3.12
		36-40(B)	-	-	-	3.28
Sri Lanka	151.23	0-10.1	24	2	40.28	2.27
		36-40(B)	14	2	20.12	3.20
South Africa	181.25	0-10.1	41	1	37.12	3.48
		36-40(B)	22	0	19.23	3.40
England	190.13	0-10.1	52	1	39.28	3.17
		36-40(B)	19	0	16.46	3.22
MEAN(SD)	**169±39.65**		**35±16.06**	**1.07±0.96**	**29.63±11.04**	**3.19±0.28**

(B) refers to the batting power play; (SD) = standard deviation; (min) =minutes

The ODI batting innings was further broken down into the first 25 overs and the second 25 overs. The mean of the runs scored during the first half of the innings was 103±21.45 in 96.57±10.63 minutes with 2.75±2.05 wickets lost. The second half of the innings had a mean of 124±67.41 runs scored in 82.65±13.82 minutes with 5.29±1.89 wickets being taken (Table 3).

Table 4: Mean and SD of the first and second 25 overs of eight ODI batting innings

Batting Team	1st 25 overs			2nd 25 overs			Total Runs Scored
	Number of runs scored	Number of wickets	Duration (min)	Number of runs scored	Number of wickets	Duration (min)	
West Indies	104	5	104.54	103	4	89.49	207
New Zealand	84	6	98.26	75	4	76.45	159
England	133	1	111.98	240	4	89.49	373
South Africa	128	0	104.85	177	9	76.45	305
South Africa	104	2	78.28	-	-	-	104
Sri Lanka	67	4	93.36	34	6	57.03	101
South Africa	97	2	89.32	121	4	91.53	218
England	104	2	92.00	117	6	98.13	221
MEAN(SD)	**103±21.45**	**2.75±2.05**	**96.57±10.63**	**124±67.41**	**5.29±1.89**	**82.65±13.82**	**211±93.73**

(min) refers to minutes; (SD) = standard deviation

4.1.3 T20 bowling innings

The motion demands of six T20 matches were analysed and separated into the bowling and batting innings. The innings analysed were separated into different tournaments, being the 2012 and 2016 T20 world cup and a T20 series in 2016 (Table 4) and separated by country. Six countries (teams) were included in the analysis (Table 5). The mean duration of the game decreased from 2012 to 2016 (from 82.34 minutes to 70.22 minutes), with a total mean time for all games being 75.50±8.31 minutes (Table 4). On average, across all the tournaments, there were 25.58±1.64 seconds between deliveries.

Table 5: Mean and SD of the motion demands of the bowling innings of T20 tournaments from 2012-2016

Type	Duration of Innings (min)	Time Between Deliveries (s)	Time for Complete Over (min)	Time for Change of Over (min)	Time for Change of Bowler (min)
T20 world cup 2012	82.34	26.01	2.33	1.01	1.20
T20 world cup 2016	77.19	25.65	2.50	1.03	1.14
T20 series 2016	70.22	25.26	2.55	0.55	1.04
MEAN(SD)	**75.50±8.31**	**25.58±1.64**	**2.52±0.27**	**0.59±0.29**	**1.12±0.09**

(s) refers to seconds; (SD) = standard deviation; (min) =minutes

The Proteas ladies spent 26.98 seconds between deliveries and had 56 seconds between overs (Table 5). England had the shortest time between overs and when changing bowlers; 0.55 minutes and one minute respectively. New Zealand spent the longest amount of time changing bowlers (1.28 minutes); however, they had the quickest time between deliveries (23.73 seconds) and subsequently, the quickest time to complete an over (2.24 minutes). Sri Lanka had the highest values for the time between deliveries and time to complete an over (28.04 seconds and 3.01 minutes, respectively).

Table 6: Breakdown of the T20 bowling innings for each country analysed

Bowling Team	Duration of Innings	Time Between Deliveries (s)	Time for Complete Over (min)	Time for Change of Over (min)	Time for Change of Bowler (min)
West Indies	78.55	25.93	2.47	1.05	1.22
Australia	73.04	24.95	2.33	1.06	1.10
South Africa	73.27	26.98	2.57	0.56	1.06
Sri Lanka	88.54	28.04	3.01	1.07	1.26
New Zealand	78.07	23.73	2.24	1.28	1.16
England	72.23	24.01	2.58	0.55	1.00
MEAN	**77.28**	**25.61**	**2.53**	**1.06**	**1.13**

(s) refers to seconds; (min) =minutes

4.1.4 T20 batting innings

On average, the run total increased between 2012 and 2016 (from 101 runs to 140 runs), with a mean value of 122±22.60 runs scored (Table 6). The power play was played for the first six overs of the innings and a mean of 37±14.24 runs was scored; the power play lasted 24.35±1.57 mins with 1.45±1.29 wickets being taken.

Table 7: Mean and SD of the motion demands of the batting innings of T20 tournaments from 2012-2016

Type	Total runs scored	Power Play		
		Number of runs	Number of wickets	Duration(min)
T20 world cup 2012	101	27	2	20.26
T20 world cup 2016	120	37	1	22.34
T20 series 2016	140	44	2	24.35
MEAN(SD)	**122±22.60**	**37±14.24**	**1.45±1.29**	**22.36±1.57**

(min) refers to minutes; (SD) =standard deviation

A mean of 59±17.95 runs was scored in the first 10 overs and 65±16.05 runs were scored in the last 10 overs of the innings (Table 7). The duration of the first and last 10 overs were 37.41±2.48 minutes and 38.53±6.26 minutes, respectively.

Table 8: Mean and SD of the first and second 10 overs in the batting innings of T20 tournaments between 2012 and 2016

Type	1st 10 Overs			2nd 10 overs		
	Number of runs	Number of wickets	Duration(min)	Number of runs	Number of wickets	Duration(min)
T20 world cup 2012	50	3.50	37.02	52	5.0	43.52
T20 world cup 2016	57	1.83	37.24	63	3.7	38.51
T20 series 2016	70	2.33	37.59	84	2.5	35.21
MEAN(SD)	**59±17.95**	**2.27±1.19**	**37.41±2.48**	**65±16.05**	**3.70±1.57**	**38.53±6.26**

(min) refers to minutes; (SD) =standard deviation

When comparing countries, England had the highest run total of 145 runs and New Zealand had the lowest of 104. Australia lost the most wickets in the power play, 2.33 (Table 8).

Table 9: Breakdown of the T20 batting innings (power play) for each country

Country	Duration of Innings(min)	Total runs scored	Power Play		
			Number of runs	Number of wickets	Duration(min)
Australia	78.39	122	32	2.3	21.55
West Indies	80.48	118	34	1.0	22.37
Sri Lanka	81.37	114	32	1.0	24.54
South Africa	80.39	118	31	1.5	24.34
New Zealand	58.16	104	44	0	20.15
England	69.22	145	53	1.5	23.43
MEAN	**75.07**	**120**	**38**	**1.22**	**23.13**

(min) refers to minutes

All countries lost more wickets in the second half of the innings when compared to the first (Table 9). England and Australia scored the most runs in the second half of the innings with 86 and 70 runs, respectively. England and New Zealand scored the most runs in the first half of the innings with 81 and 64 runs, respectively.

Table 10: Breakdown of the first and second 10 overs in the T20 batting innings for each country

Country	First 10 Overs			Second 10 overs		
	Number of runs	Number of wickets	Duration(min)	Number of runs	Number of wickets	Duration(min)
Australia	52	2.67	35.39	70	4	41.12
West Indies	61	2	37.30	57	4	42.53
Sri Lanka	50	2	41.42	64	5	39.07
South Africa	50	2.5	38.25	68	3	40.35
New Zealand	64	2	34.00	40	2	23.24
England	81	2	38.39	86	4	37.07
MEAN	**60**	**2.2**	**37.46**	**64**	**3.67**	**37.23**

(min) refers to minutes

4.2 ODI century and T20 half-century breakdown

4.2.1 ODI century breakdown

The century breakdown was taken from all centuries scored by the top 10 countries in the women's ICC world rankings between June 2008 and May 2017. The mean runs scored was 115±16.36 runs off 122.03±16.92 balls in 159.10±22.14 minutes with a run rate of 5.74±0.84. It was found that 58±16.15 runs were scored off boundaries (fours and sixes) and 58±13.19 runs were scored off non-boundaries (ones, twos, and threes) (Table 10). It took, on average, 62.53 balls to score the first 50 in 84.36 minutes and 55.77 balls in 61 minutes to score the second 50 runs (Table 11). It, therefore, took 113 balls in 145 minutes to score an ODI century.

Table 11: Breakdown of all scores above 100 scored by countries listed in the top 10 of the ICC rankings.

	Team Total	Runs	Duration (min)	Balls Faced	Over	Strike Rate	Partnership
Mean	267.44	115	159.10	122.03	20.34	95.65	223.06
SD	47.96	16.36	22.14	16.92	2.82	14.05	40.19

(min) refers to minutes

Table 12: Breakdown of a century, into the first and second half century, scored by male and female batters (Men's data taken from Duffield & Drinkwater, 2011)

	First 50 runs		Second 50 runs	
	Duration (min)	**Balls Faced**	**Duration (min)**	**Balls Faced**
Male	84.50	64	51	38
Female	84.36	63	61	56

(min) refers to minutes

Figure 2 shows the mean breakdown of the runs scored in a century for all of the countries in the top 10 of the ICC rankings. The breakdown was as follows: 43±10.26 singles, 6±3.05 twos, 0.59±0.88 threes, 14±4.53 fours and 0.82±1.52 sixes. Of the 122 balls faced there were, on average, 57.79±15.17 dot balls.

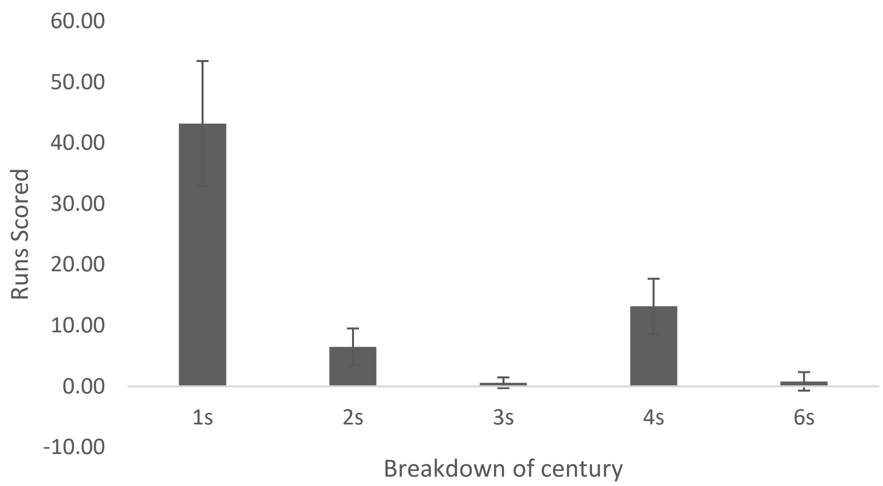

Figure 2: Breakdown of scores above 100 from the countries listed in the top 10 of the ICC rankings

Table 12 represents the breakdown of scores above 100 for each country in the top 10. England had the highest mean score of 123 and the highest team total of 316 runs. South Africa had a mean score of 106 runs with a team total of 236 runs. South African players score centuries in the fastest time with the fewest balls (123 runs in 133 minutes off 104 balls) and therefore had the highest strike rate (102.75). There were, however, no statistical differences between any of the variables and between countries.

Table 13: Breakdown of centuries scored by each country

Country	Team Total	Runs	Duration (min)	Balls Faced	Over	Strike Rate	1s	2s	3s	4s	6s
England	316	123	165	123.63	20.60	98.78	44	6	0	16	1
New Zealand	271	117	152	118.88	19.81	99.43	41	8	1	14	0
Pakistan	266	116	143	128.33	21.39	93.38	42	7	0	15	0
Australia	258	115	159	119.63	19.94	96.66	47	6	1	12	1
West Indies	181	107	169	127.50	21.25	84.19	29	10	1	10	3
South Africa	236	106	133	104.50	17.42	102.75	35	7	2	11	2
India	257	106	171	127.50	21.25	84.40	48	3	0	10	2
MEAN	**256**	**113**	**155**	**121.42**	**20.23**	**94.22**	**41**	**7**	**0.71**	**13**	**1**

(min) refers to minutes

Figure 3 represents the number of centuries scored by each country in the top 10 of the ICC rankings. Australia, New Zealand, and England all scored eight centuries during this period. South Africa scored five, India scored four, Pakistan scored three and the West Indies, two. A West Indies player has not scored a century since 2013.

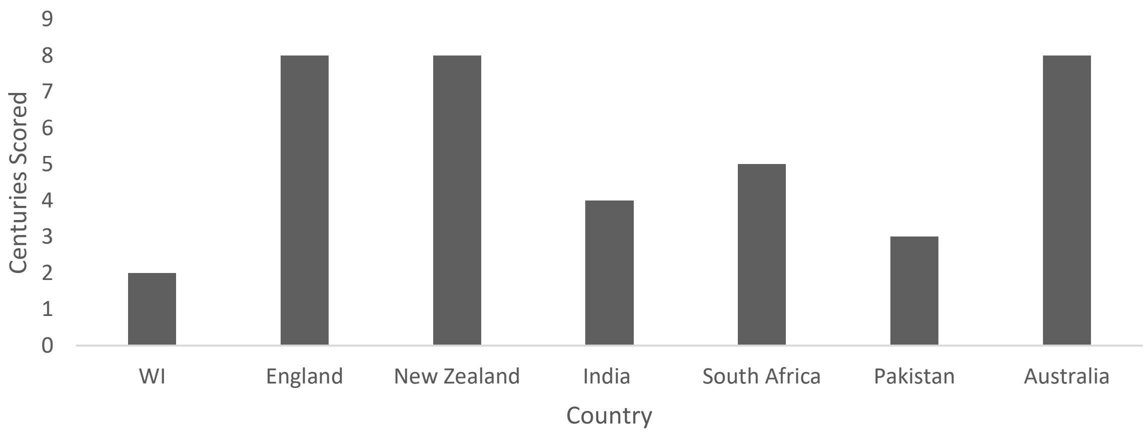

Figure 3: Number of centuries scored by each country in the top 10 of the ICC world rankings

4.2.2 T20 half-century

The T20 breakdown was taken from the mean of the run totals greater than 50, scored by the top 10 teams in the women's ICC world rankings from 2008 to February 2017. The mean runs scored was 63±12.80 off 50.05±8.09 balls in 60.04±10.26 minutes with a run rate of 7.61±1.34. Of the total runs scored, 34±11.80 were scored off boundaries (fours and sixes) and 29±7.61 runs were scored off non-boundaries (ones, twos, and threes) (Table 13).

Table 14: Breakdown of T20 runs scored by all countries

	Team Total	Runs	Duration(min)	Balls Faced	Over	Strike Rate	Partnership
Mean	140	62.82	60.04	50.05	8.34	126.45	115.22
SD	23.86	12.80	10.26	8.09	1.35	22.34	26.54

(min) refers to minutes

Figure 4 represents the mean breakdown of runs scored in a T20 match by all of the countries listed.

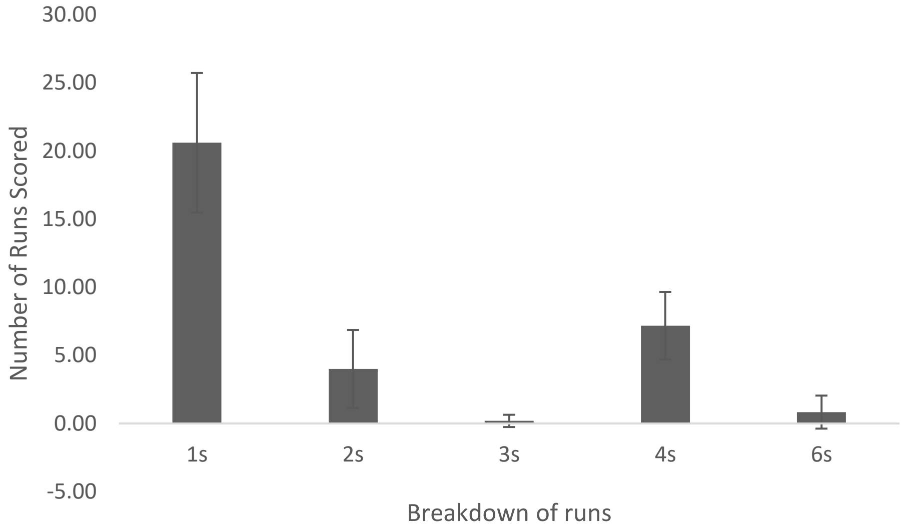

Figure 4: Mean breakdown of T20 scores by countries ranked in the top 10 of the ICC recorded between 2008 and 2017

England achieved the most individual run totals over 50, with 19. This was followed by Australia with 17, the West Indies with 13, South Africa with 11, New Zealand with seven, Pakistan and India both with five and Sri Lanka with the least, four (Figure 5).

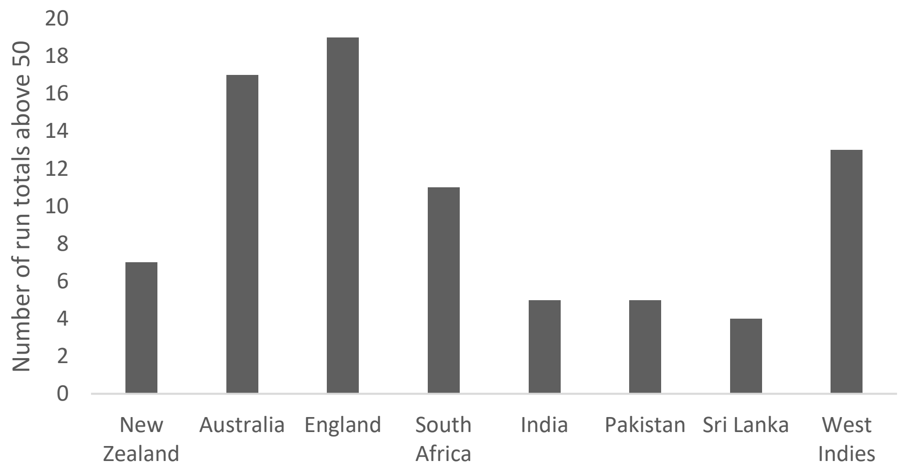

Figure 5: Number of T20 individual run totals above 50 for each country

4.3 ODI century and T20 half-century breakdown for South Africa

4.3.1 ODI century

From 2013 to May 2017, only five centuries were scored by a South African batter (Appendix C). Three were scored against Ireland, one against Bangladesh and one against Australia. Of the 114±20.31 runs scored, 56±11.35 runs were scored off boundaries (fours and sixes) and 58±16.84 runs were scored off non-boundaries (ones, twos, and threes) with a run rate of 6.13±0.83. On average, 40 runs were scored off singles, 15 off twos, 4 off threes, 48 runs off fours and 8 runs off sixes. Across the five centuries scored, however, only one batter hit sixes. The average batter was at the crease for 144.5±24.56 minutes with a partnership total of 209±50.86 runs. It took 61±12.73 balls in 83.5±2.12 minutes to score a half century and 114±12.73 balls in 139.5±9.19 minutes to score a century.

Table 15: Breakdown of scores above 100 achieved by South African batters

	Team total	Runs	Duration (min)	Balls Faced	Strike Rate	Partnership
Mean	256	114	144.5	113	102.20	209
SD	59	20	24.6	23	13.81	51

(min) refers to minutes

Figure 6 represents the mean breakdown of runs scored in an ODI century by South Africa. Of the 113.4 balls faced, 51.2±15.43 were dot balls for which no runs were scored.

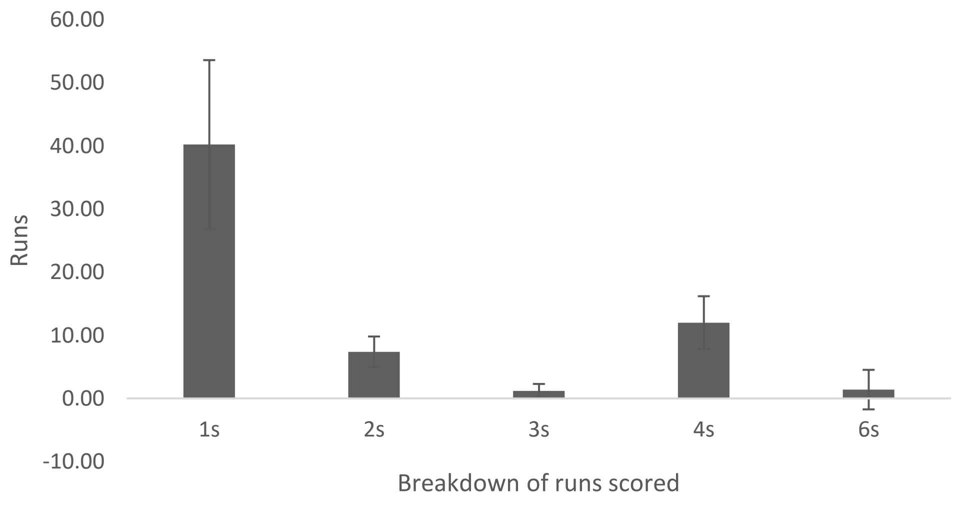

Figure 6: Breakdown of scores above 100 scored by South Africa

4.3.2 T20 half-century

From 2013 to February 2017, only 10 batters scored above 50 runs, with the run total of 70 being the highest recorded (Appendix D). Of the 57±8.20 runs scored, 27±9.87 were scored off boundaries (fours and sixes) and 30±3.96 runs were scored off non-boundaries (ones, twos, and threes) with a run rate of 6.59±1.39. On average, 21 runs were scored off singles, 8 off twos, 0.27 off threes, 23 runs off fours and 4 runs off sixes. The average South African batter is at the crease for 57.40±9.08 minutes accumulating a partnership total of 102.45±17.26 runs.

Table 16: Breakdown of South African T20 half centuries (scores above 50)

	Team Total	Runs	Duration (min)	Balls Faced	Strike Rate	Partnership
Mean	125	57	57.40	53.64	105.91	102
SD	13.09	8.20	9.08	11.01	19.93	17.26

(min) refers to minutes

Figure 7 represents the mean breakdown of runs scored by South Africa in T20 matches, based on a mean of 57 runs. Of the 53.64 balls faced, there were on average 21.64±10.10 dot balls.

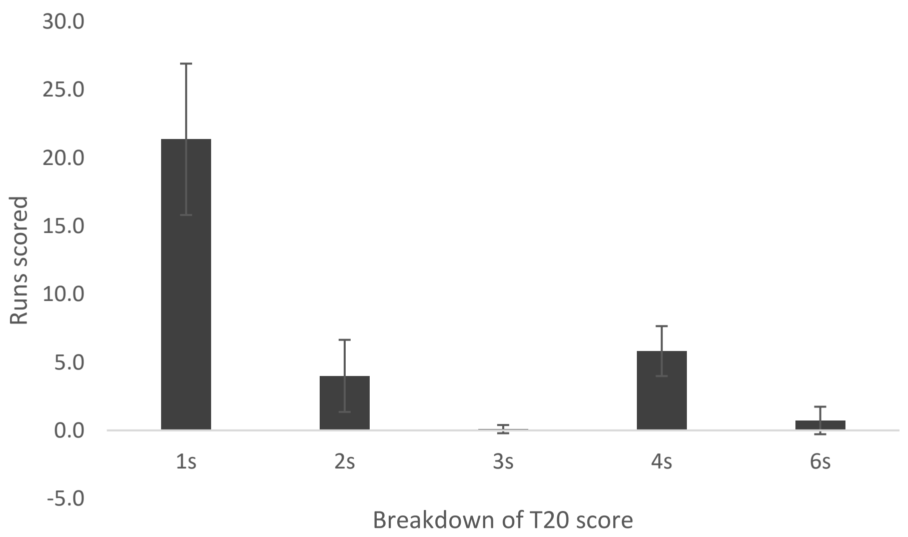

Figure 7: Breakdown of T20 scores above 50 by South Africa

4.4 Statistical analyses

4.4.1 Comparing the ODI and T20 bowling innings

The difference in time between deliveries (p=0.0146) and the time for change of the bowler was significantly (p=0.0181) greater and more varied in the ODI format (Figure 8).

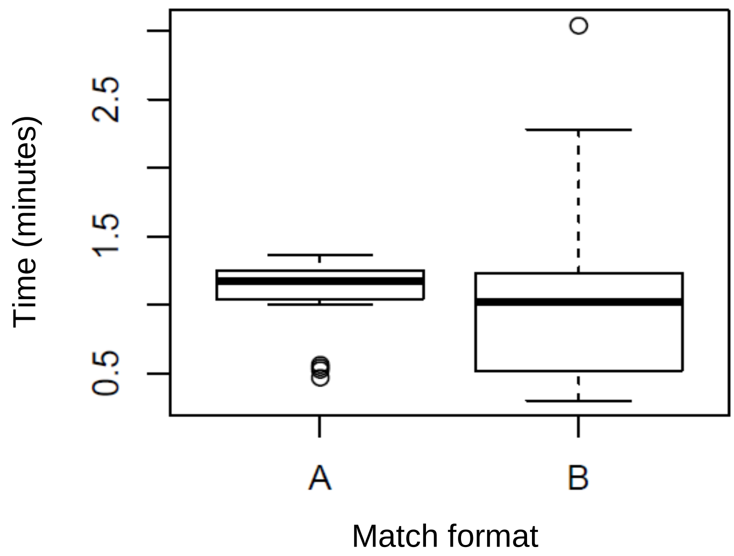

Figure 8: Boxplot indicating the variation in time when changing bowlers comparing ODI and T20 format (A=ODI and B=T20)

4.4.2 Difference between countries in the ODI bowling innings

The time between deliveries for South Africa was significantly shorter than England (p=0.00045), Sri Lanka (p=0.002), the West Indies (p=0.001) and New Zealand (p=0.001) (Figure (9).

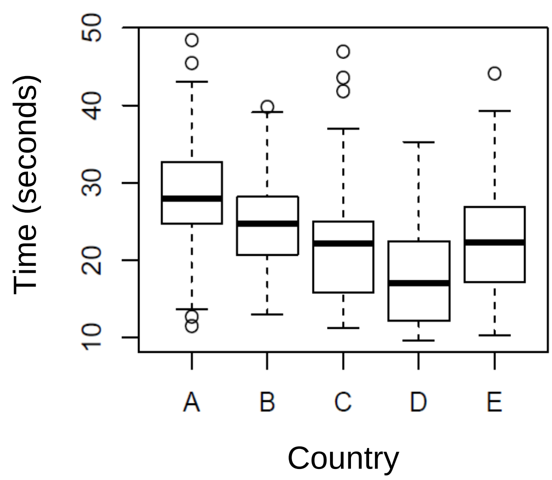

Figure 9: Boxplot representing the time between deliveries for each country in the ODI bowling innings (A=South Africa, B=England, C=Sri Lanka, D=the West Indies and E= New Zealand.)

The difference in time for change of bowler for South Africa was significantly shorter and more varied than England (p=0.011), Sri Lanka (p=0.0046), the West Indies (p=0.0015) and New Zealand (p=0.0031) (Figure 10).

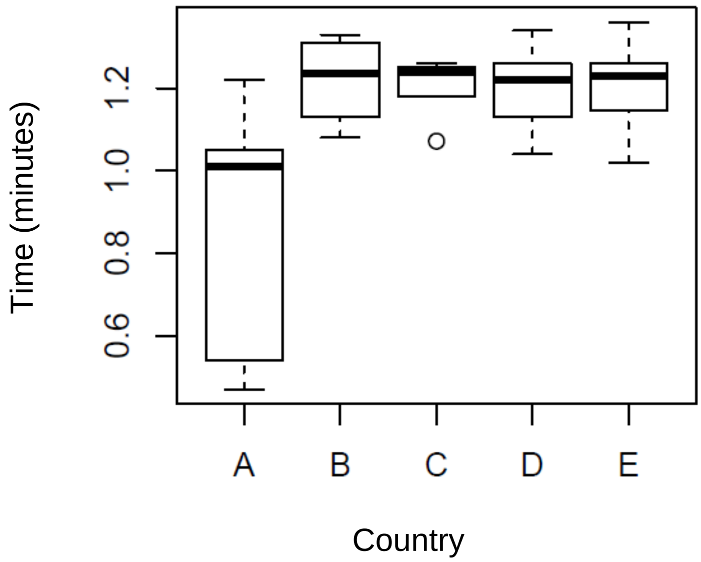

Figure 10: Boxplot representing the time taken when changing bowlers for each country in the ODI format (A=South Africa, B=England, C=Sri Lanka, D=the West Indies and E= New Zealand.)

4.4.3 Difference between countries in the T20 bowling innings

The time between deliveries of Australia (24.93s) was significantly longer than the West Indies (21.82s) (p=0.000009) and New Zealand (22.26s) (p=0.0003). South Africa had the highest value of 26.93s, which was significantly longer than Australia (p=0.03), the West Indies (p=0.001) and New Zealand (p=0.001). Furthermore, England (23.79s) was significantly shorter than South Africa (p=0.002) and Sri Lanka (28.04s) was significantly longer than the West Indies (p=0.001), New Zealand (p=0.001), Australia (p=0.007) and England (p=0.0005).

The time for change of the bowler for South Africa was significantly shorter than the West Indies (p=0.0000001), New Zealand (p=0.00002) and Australia (p=0.0005). England took significantly longer than the West Indies (p=0.0006) and New Zealand (p=0.0042). Sri Lanka took significantly longer than South Africa (p=0.00003) and significantly shorter than England (p=0.0027).

The time between deliveries and time for change of bowler is significantly different with regards to both the format of the game and the countries analysed.

4.4.4 ODI century comparison between each country and the years ranging from 2009-2017

There were no statistically significant differences between any of the variables in the ODI century analysis across all countries between 2009 and 2017.

4.4.5 T20 run breakdown comparison between each country and from the years 2012-2017

South Africa's strike rates were significantly lower than Australia (p=0.0022), England (p=0.04) and New Zealand (p=0.02). New Zealand scored significantly more twos than Australia (p=0.042), the West Indies (p=0.02) and Sri Lanka (p=0.034). There were significant differences between all countries in the number of fours scored (p=0.007), the number of sixes scored (p=0.005) and the number of dot balls (p=0.04); however, there were no specific differences between individual countries (Figure 11).

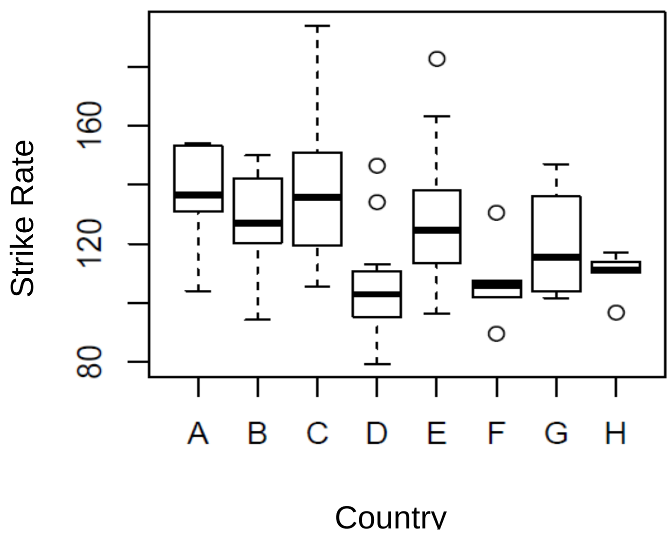

Figure 11: Boxplot of the strike rates of different countries when scoring a T20 half century (A=New Zealand, B=England, C=Australia, D=South Africa, E=the West Indies, F=India, G=Sri Lanka and H=Pakistan).

There were significant differences in the number of threes scored across all the years (p=0.0007) and significant differences between 2012 and the years 2013 (p=0.01), 2014 (p=0.002), 2015 (p=0.006) and 2016 (p=0.0009). Between 2013 and 2016, only "three" runs were recorded for four batters. All other variables were found not to be statistically significant.

4.5 Protocol design (W-BATEX)

The protocol was designed based on the mean values of all countries analysed in the time motion analyses and the century run breakdown. As the variables have been recorded for different countries, the protocol can be adapted to each country if necessary. The protocol, however, needs to be tested in order to be evaluated.

The following recorded variables were used in the protocol design:

- The total deliveries faced when scoring a century was 113, however, the protocol will last 20 overs (120 deliveries) for ease of use.
- The time between deliveries was 25 seconds with one minute between each over (this includes the possibility of changing bowlers in between overs).
- The percentage of boundaries and non-boundaries scored was 50%, respectively.
- Of the 113 deliveries faced, 47% of the deliveries were dot balls
- Singles accounted for 38%, twos for 11%, threes for 2%, fours for 45% and sixes accounted for 5% of the mean century breakdown.
- The first 50 runs of the century were scored in 62 deliveries and the second 50 was scored in only 55 deliveries.

Therefore, the protocol has four different stages completed within a total of 20 overs. A ball is delivered every 32 seconds (i.e. 25 seconds in between deliveries and seven seconds for the actual delivery). The batter is given 60 seconds between each over to recover. Each over will last 3 minutes 47 seconds. Each stage will, therefore, last 18 minutes 55 seconds therefore, the protocol will last 1 hour and 5 minutes and 40 seconds. This duration is shorter than the average time taken to score a century as it does not take partnership totals into consideration.

The breakdown of runs utilised in the protocol can be seen in Table 16.

Table 17: Breakdown of runs in a century utilised in the simulated protocol

Singles	Twos	Threes	Fours	Dot balls
35	6	1	13	58

The total number of runs scored in this protocol is 102 off 120 deliveries. No sixes are included in the protocol as the batter would not run between the wickets. Similar to that of the BATEX© protocol, batters will run at maximal speed in stages two and four and at a self-selected pace in stages one and three. Although each stage is based on a different format/stage of the game, overall, the physical workload is designed to reflect the mean run distribution of an ODI century. The different running requirements in the stages replicate that of an actual match scenario, representing the low and high-risk scenarios. The running requirements during each stage of the simulated batting innings are based on the typical running-between-the-wickets patterns of male batters ascertained from Houghton and colleagues (2011). The male data was used as the running-between-the-wickets patterns of female batters was not available and could not be studied in this research study due to the limited camera angles in the televised matches analysed. The matches utilised in the motion analysis did not include batters scoring centuries due to the limited sample, therefore all running requirements are based on data taken from CricInfo. The simulated protocol that was established utilised the information above and can be seen in Table 17 below.

Table 18: Simulated batting protocol specifically designed for female batters (W-BATEX) (adapted from the BATEX© protocol by Houghton *et al.* (2011)).

Stage	Runs completed in each over				
	Over 1	Over 2	Over 3	Over 4	Over 5
1. Building Momentum (low intensity)	1,1,1	1	1,1,2	No runs	1,4
2. Power Play (high intensity)	1,1,1	1,1,4	1,1,4,4	1,1,2,3	4,2,1
3. Maintaining Tempo (low intensity)	1,2	No runs	1,1,4	1,1,2	1,1,1
4. Closing of the Innings (high intensity)	1,1,4	1,1,2,4	1,1,4,1	1,1,4,4	1,4,1,4

The batter will be required to complete the instructed runs (Table 17) in any order within the over but is encouraged to match the runs with the shot played. As data was not available to ascertain the complete over by over run-breakdown of scoring a century (due to this information being taken from CricInfo), the method by Houghton *et al.* (2011) of allowing the batter to score the required runs in any order was used. Running a ‘‘4’’ is equivalent to running 1.5 runs (i.e. one run and a turn), which may occur in a match if the batter attempts to accumulate runs before the ball crosses the boundary (Houghton *et al*., 2011).

In order to simulate the overall demands of scoring a century with another batter at the crease, the protocol should be done by two batters at a time.

4.6 Summary of results

The time-motion analyses indicated that the duration of an ODI and T20 innings was 169 minutes and 75.50 minutes, respectively. An over lasted 2.45 minutes (ODI) and 2.52 minutes (T20), with 24.86 seconds (ODI) and 25.58 seconds (T20) between each delivery and 55 seconds between each over (ODI). When the bowling side changed to a new bowler, it was 1.12 minutes between overs (ODI and T20). The mean score in the batting innings was 211 runs (ODI) and 122 runs (T20). The mean score for the first power play in an ODI consisted of 41 runs with 1.38 wickets being taken. The mean score during the second power play (ODI) was 28 runs with 0.7 wickets being taken. The T20 power play had a mean of 37 runs scored with 1.45 wickets being taken. The time between deliveries and time for change of bowler was significantly different between the ODI and T20 formats as well as between certain countries.

The ODI century breakdown indicated that to score a century would take 113 balls in 145 minutes. It took on average 62.53 balls in 84.36 minutes to score the first 50 and 55.77 balls in 61 minutes to score the second 50 runs.

The simulated batting innings was then designed as four stages lasting the duration of a typical women's century. Each stage was based on theoretical phases of play that may occur during a batting innings.

CHAPTER V

Discussion

This study is the first to attempt to analyse and quantify the motion demands of the batting and bowling innings of ODI and T20 matches for women's cricket. It is important to note that the sample size was limited owing to the limited availability of past matches and very few full women's matches being televised. Coverage has, however, improved as the popularity of the women's game has increased.

5.1 ODI bowling innings

The findings of the time-motion analyses of the ODI bowling innings can be seen in Table 1 (page 31). The duration of the innings was, on average, an hour faster than an average men's ODI match. This may affect the number of possible runs or centuries scored, as the mean time taken by a female batter to score a century was 145 minutes. The difference in duration between overs and for a change in bowler, was 17 seconds, which could be due to the bowler and the captain altering the fielding placements to better suit the bowling style of the new bowler. This would be done in an attempt to reduce the number of runs scored or to obtain a wicket by increasing the pressure on the batter.

The time between deliveries was much shorter for female bowlers than that for male bowlers (Houghton *et al.* 2011; Duffield & Drinkwater, 2008; CricInfo). Male batters have 35 seconds to prepare for the next delivery, which is 10 seconds longer than female batters have. The reason for this could be due to males having a longer run-up, or because of changing fielding placements between deliveries instead of between overs. Another probable cause of the shorter time could be that female cricketers play on a smaller field, where the boundary rope is only 50-60 metres from the pitch. The time between overs was slightly longer in the men's game (80 seconds) (Houghton *et al.*, 2011) than the women's game (55 seconds). This is an important finding as this shorter duration between deliveries and time to complete an over in the women's game will decrease the likelihood of a team exceeding the over rate. The over rate is the set amount of time allocated to complete an innings. If the bowling team exceeds this over rate, the captain and/or team can be fined.

The innings, which was broken up into the first 25 and second 25 overs, can be viewed in Table 3 (page 32). The number of wickets taken was higher in the second 25 overs when compared to the first. This could be attributed to greater risk taking in the second half of the game to reach a higher total. Furthermore, there may be a greater chance of female bottom-order batters being at the crease in the second half of the innings, thus increasing their chances of getting out, or a greater chance that the batting side is attempting to chase a run total with limited overs remaining. These reasons, coupled with the limited time between deliveries, which results in less time to recuperate and regain focus, might be a possible cause of the increase in the number of wickets lost in the second 25 overs. The physiological characteristics of female batters have not been researched and thus, whether female batters fatigue to a greater extent than their male counterparts at the end of the innings is only speculation. Although fatigue is expected to occur (Noakes & Durandt, 2000), the rate and point in time at which this occurs for female batters is not yet known.

Country comparisons show that South Africa had the slowest time between deliveries (28.57 seconds), and this was statistically significant compared to all of the other countries. This may be because South Africa alters its fielding placements more frequently between each ball or because more boundaries are scored against South Africa (as can be seen in Appendix B, when centuries are scored against South Africa, 16 boundaries, on average, are scored) and thus, it takes longer for the ball to be returned to the bowler. Alternatively, it could be because South African bowlers have longer run-ups, although this is speculation and needs to be investigated further. England had the shortest time between deliveries when compared to New Zealand and the West Indies. England has fewer fast bowlers and, subsequently, will have shorter run-ups.

5.2 ODI batting innings

The mean number of runs scored in women's matches was 211 runs, which is considered low for 50 overs of cricket, and could be because fewer sixes are scored in the women's game (Duffield & Drinkwater, 2008). Furthermore, women do not score as many threes as men since the boundary rope is closer to the pitch. As a result, they run a greater number of singles and doubles as they have less time to run across the pitch before the ball is returned to the stumps. It may also be possible that the number of boundaries (fours and sixes) is limited in the women's game since there is a lack of pace on the ball since female fast bowlers do not bowl at speeds that are as high as their male counterparts (Bartlett *et al.*, 1996; Savage & Portus, 2002). The batter would, therefore, need to hit the ball with greater force to reach the boundary. It should be noted, however, that the century breakdown analyses indicated a much higher team total compared to that obtained from the matches used in the time-motion analyses. This difference may be owing to the limited sample size in the motion analyses. The mean team score in the century breakdown was 267 runs, which is 56 runs more than that found in the time-motion analysis and may be a more accurate representation of the team totals by all countries in an ODI innings.

When the batting innings is broken down, it comprises two power plays during which only two fielders are allowed outside of the 30-yard circle, creating more opportunities for boundaries and greater entertainment for the crowd. The first power play takes place during the first 10 overs of the innings whereas the second is only four overs long and is generally taken between the 36^{th} and 40^{th} overs; this power play is known as the batting power play. Thus, female batters are probably more cautious with their wickets during the second power play when compared to the first power play as only 0.7 wickets are lost in the second, while 1.38 are lost in the first. This could be because, during the second power play, the bowling side are not utilising their best bowlers since the number of runs scored in the second power play is only 13 runs less than the first, which comprises 10 overs (i.e. six overs longer than the second power play). The number of wickets lost in the first power play (1.38) is similar to that of their male counterparts (1.33) (CricInfo: Date accessed 23 February 2018) but, on average, an extra 10 runs are scored in the men's game. A comparison of the second power play is not possible as in the men's league, the second play lasts 10 overs as opposed to the four overs in women's cricket.

The duration of the second half of the innings (82.65 minutes) was also shorter than the first half (96.57 minutes) and the number of runs scored in the second half of the innings was 11 runs more than the first half. This difference may be a result of more 'risky' shots being played by the batters in the second 25 overs to score more runs. A mean of five wickets was lost in the second 25 overs compared to the two wickets lost in the first half of the innings. Most of the wickets taken in the second half of the innings occurred in the last 10 overs of the innings, which may be due to an increase in the possibility of lower-order batters at the crease or batters taking more risks to chase a higher run total.

In terms of the ODI batting innings, each country had varied results. With respect to the total runs scored, England scored on average 297 runs whereas South Africa scored 209 runs. New Zealand, the West Indies, and Sri Lanka, unfortunately, had only one innings analysed and therefore no mean could be calculated. The innings was, therefore, broken down into the first and second 25 overs and only England and South Africa were comparable. England scored more runs on average than South Africa in the first and second 25 overs of the innings (10 and 29 more runs, respectively). Thus, England scored a greater amount of runs overall and performed better in the second half of the innings. All countries lost more wickets in the second half of the innings when compared to the first half. South Africa lost up to 6.5 wickets in the second 25 overs of the innings. This could be due to a lack of skilled batters in the South African team or the conditioning of the players may not be adequate, resulting in fatigue at the end of the innings. Alternatively, the opposition may be making better bowling and fielding-placement decisions. This observation is, however, based on four innings and is only speculation.

5.3 T20 bowling innings

The findings of the T20 bowling innings motion analyses can be seen in Table 5. The mean time for the change of bowlers was the same for the ODI and T20 innings (1.12 minutes); however, due to the large variation in the T20 data, seen in Figure 8, the difference was statistically significant. This large variation may indicate that fielding changes occur more frequently during T20 matches when a new bowler comes into the attack. The captain will, therefore, adjust the field according to the bowler and the batter at the crease, thus increasing the time before the next over begins. It may also suggest that the team was not properly prepared to adjust the field according to the new bowler and that the captain/bowler had to make these changes manually. All other variables were longer in duration but were not statistically significant. The longer duration of the variables may be owing to the T20 format consisting of 20 overs and, due to the limited overs, more boundaries would be expected to occur to reach a higher run total in a shorter period. This would increase the time taken for the ball to be thrown back to the bowler, which would subsequently increase the time for the over to be completed.

If we compare the different tournaments, that is, a T20 world cup and a regular T20 series, the duration of all variables is greater in the world cup matches when compared to the series matches (Table 4). This may be due to the greater pressure to win world cup matches, resulting in more constant bowling and fielding changes. Another probable cause is the specific countries that took part in the matches analysed. The T20 series between South Africa and England can be seen in Table 5, showing that England had very quick times for most of the variables, which would subsequently result in a shorter bowling innings.

5.4 T20 batting innings

The T20 innings was broken up into three different tournaments. The data collected for each tournament's batting innings are represented in Table 6. The team run total increased from 101 runs in 2012 to 140 runs 2016. In addition, all variables recorded in the batting innings increased between 2012 and 2016; however, none was statistically significant. These findings may, therefore, indicate that this form of the game has changed over the years but, due to the limited sample size, this is only speculation. It is evident, however, that higher totals are scored by men in the T20 format then their female counterparts. In the 2017/2018 season, the mean team total was 155 runs, with a mean of 49 runs scored in the power play (CricInfo: Date accessed 23 February 2018).

The T20 format consists of one power play, which is played in the first six overs of the innings. The mean loss of wickets (1.45) was similar to that of the first power play in the ODI format (1.38). However, the ODI power play lasts for 10 overs, which may suggest that batters are more likely to lose wickets more quickly in the T20 format since they may take greater risks to achieve higher run totals within the limited overs. This is seen in the men's format as well, where the mean loss of wickets in the T20 and ODI formats were 1.44 and 1.33, respectively (CricInfo: Date accessed 23 February 2018).

The T20 batting innings was broken down into the first 10 overs and the last 10 overs. A mean of 59.36 runs was scored in the first 10 overs and 64.90 runs were scored in the last 10 overs of the innings. If the first half-century and second half-century in an ODI century are compared to the half-century scored in the T20 format, the half-century in the T20 format was achieved faster than the first and second 50 runs scored in both a men's and women's ODI century (Table 8). The women's T20 half-century was, however, similar to that of the men's ODI second half-century suggesting that during a T20 match, female batters use similar tactics to that of male batters when scoring a century in an ODI match.

All countries lost more wickets in the second half of the innings when compared to the first (Table 9). The Australian women lost the most wickets (2.33) in the power play, which is much greater than the Australian men's team who lost 1.5 in the T20 power play (CricInfo: Date accessed 23 February 2018). The Australian women's side had the highest number of wickets lost in the 10 overs across all countries. This may be because Australian female batters may take greater risks in the T20 format. This is, however, based on 2012 and 2016 data and their game style may have changed and improved after the inclusion of the WBBL.

5.5 ODI century breakdown

As the breakdown of a century was not possible due to the limited information available on CricInfo, all scores above 100 were recorded from 2008 to 2017. The mean score was 115 runs off 122 balls in 159 minutes. There were, however, a few batters that scored 100 runs (n=16) and 100 runs were scored off a mean of 113 balls in 145 minutes. Fifty percent of the runs scored were from boundaries. Male batters take, on average, 135.5 minutes off 102 balls to score a century (Duffield & Drinkwater, 2008), Noakes & Durandt, 2000). The longer duration and increased number of balls faced by women may be due to the increased number of singles and doubles run by the female batters instead of the higher number of threes and sixes achieved by their male counterparts. The difference in the duration of the innings is interesting to note here as it indicates that even though female batters take longer to reach 100 runs, their innings will still be completed before that of their male counter-parts.

The century was divided into the first 50 runs and the second 50 runs scored. Female batters take less time to score the second 50 runs compared to the first 50 runs (Table 11). There was, however, a difference in time taken and deliveries faced between male and female batters in the second 50 runs scored (Table 11). The mean century scored by a male batter, according to Duffield and Drinkwater (2011), consisted of 64 deliveries in 84.5 minutes to score the first 50 runs and 38 deliveries in 51 minutes for the second 50 runs (Table 11). Both male and female batters take, on average, the same number of balls and duration to score the first 50 runs; however, female batters take 10 minutes longer off approximately an extra 18 deliveries to score the second 50. The reason for this is not clear although it may suggest that female batters fatigue to a greater extent than male batters thus resulting in fewer “big hits”. The lack of “big hits” may also be explained by the lack of pace on the ball as female fast bowlers do not bowl at speeds that are as high as their male fast bowler counterparts (Bartlett *et al.*, 1996; Savage & Portus, 2002). As a result, the batter would need to hit the ball with greater force to reach the boundary and may not be conditioned enough to do so. Another possible reason is the increased number of dot balls indicating female batters may take fewer risks after achieving a half-century. However, this would need to be investigated further.

Although it is difficult to compare this to the century breakdown by Duffield and Drinkwater (2011), the comparison may still be of value. The clearest differences are between the numbers of threes run by female and male batters. Females score, on average 0.5 threes, whereas male batters score 3 threes, when scoring a century. This difference is likely due to the closer boundary rope, which results in less time for the female batters to run between the wickets. The closer boundary rope may also explain the higher number of fours scored by females (13.5) compared to males (seven) (Duffield & Drinkwater, 2011). The comparison of dot balls was not possible, however since fewer deliveries were faced during the men’s century, female batters may have a greater number of dot balls.

The different variables, including a comparison over the years, recorded for each country that scored an ODI century were found not to be statistically different. This may suggest that not one country is “better” at scoring centuries compared to others and that the physical demands have not changed over the years; however, this does not explain why some countries score more centuries than others do. Australia, New Zealand, and England have scored the most centuries. These countries have anecdotally been known to have greater amounts of support and funding compared to other countries. Although crowd attendance and government support have increased in general for women’s cricket, these countries have been playing international cricket for a longer period. As a result, there are more young women playing the game and more funding is given to player development (Wildie, 2017). An example would be that Australia and New Zealand play against each other every year in the Rose Bowl, thus improving their cricket overall. This will subsequently increase the level of women's cricket across the world, as other countries would need to improve in order to compete with these countries. The exposure of women's cricket would grow as the game improves and as more people support it. In addition, Australia has had the inclusion of the WBBL, which has occurred for the past three seasons. The WBBL is similar to the men's league (BBL), which has been around for seven seasons. The inclusion of the WBBL and the BBL has provided young, inexperienced players the opportunity to play against the top-ranked players from around the world. This exposure will greatly improve all players who are involved and will subsequently allow for a larger selection to be included in the national side.

The WBBL has amplified public interest in women's cricket, not just in Australia but also around the world. This increased exposure has resulted in the increased likelihood of these matches being televised around the world. However, there are still many setbacks in the WBBL, some of the matches are often not televised worldwide as they are played at smaller cricket grounds, whereas all of the men's matches are televised. If young women see elite female cricketers on television, they are more likely to aspire to the same heights and this increases the chance of these young players wanting to play cricket. This has been seen in other sports, specifically the Olympics, as it was recorded after the London Olympics in 2012, that over 750000 people were taking part in sport in the country when compared to the previous year (BBC Sport, 2012). It was also noted that more women than ever before were participating in sport, although a value was not specified (BBC Sport, 2012). The increased number of people interested in cricket would result in greater pressure on the media to promote women's cricket and thus increase televised matches and subsequently have more women's matches played at larger cricket grounds. This would generate more income that could potentially be fed back into young player development and improve female sport across the country. The WBBL is only the beginning and more countries, specifically South Africa, need to follow suit to continue the momentum towards uplifting women's cricket.

This momentum would hopefully one day have women's cricket becoming a stand-alone sport and would no longer have women being compared to their male counterparts in terms of how they play or how many boundaries they score. The cricketing community should recognise and celebrate these differences and not disparage them. Both the men’s and women’s format have a lot to offer and should be valued and respected equally.

5.6 T20 half-century breakdown

The percent boundaries scored (53%) was marginally higher than the ODI breakdown (50%).

New Zealand scored significantly more twos than Australia, the West Indies, and Sri Lanka when scoring a T20 half-century. New Zealand may have had faster batters who were able to run between the wickets more quickly, or who were better conditioned. They could also have had more skilled batters who were able to select the gaps in the field thus allowing more time to run between the wickets. There were significant differences between all countries in the number of fours and sixes scored and in the number of dot balls. This may indicate that some countries had better-skilled batters and consequently scored more boundaries.

England achieved the most individual run totals over 50. The most notable difference between countries was the strike rate. The strike rate of South African batters was statistically lower than Australia, England and New Zealand, with a large variation (Figure 11, page 45). This may suggest that South African batters were not as skilled as the other batters or that they took fewer risks when batting, which resulted in an increase in dot balls. When compared to the strike rate when scoring a century, however, South Africa had the highest strike rate. The reason as to why they had the lowest strike rate in T20 matches and the highest in ODI matches is not known. However, different batters may have different playing styles depending on the format. As the T20 format is designed to increase run totals and boundaries, the strike rate should, however, be higher in these games. This is something that must be investigated further.

When comparing the runs scored over the period between 2012 and 2017, the only statistical differences were in the number of threes scored. Only four threes were scored from 2013 to 2016. This change in the number of threes run may be due to the batters being more cautious and not risking the third run.

5.7 Breakdown of South African ODI century and T20 half century

South Africans score centuries in the fastest time, with the highest strike rate. However, because very few centuries have been scored by South Africa, this is not conclusive.

Only five centuries were scored by South African batters (Appendix E). Three were scored against Ireland, one against Bangladesh and one against Australia. This was between 2009 and February 2017. This once again suggests that South African batters may not have been adequately conditioned or skilled enough to obtain this milestone, or, that the opposition's bowlers were of very high quality. South African batters scored, on average, 114 runs if they went on to get above 100 runs. Across the centuries scored, however, only one of the five batters hit a six. The average South African batter was at the crease for 144.5 minutes, which is very similar to the mean time spent by all female batters to achieve a century. It took 61 balls in 83.5 minutes to score a half-century, which is similar to the mean time taken by all female batters seen in the century breakdown. Other countries took 109 balls to score a century when playing against South Africa, which is less than the overall mean of 113 balls. This was probably due to the high number of boundaries scored against South Africa (Appendix B). This may, however, have changed in recent years as South Africa has produced some of the best bowlers in the world more recently, including Marizanne Kapp and Dane Van Niekerk to name but a few (CricInfo: Date accessed January 25, 2018).

Only 10 South African batters scored above 50 runs, of which a run total of 70 was the highest recorded in the T20 format (Appendix E). The run rate (6.59) was slightly higher than that of the run rate in the ODI century (6.13). South Africa had the lowest strike rate, which was significantly lower than the strike rates of New Zealand, England and Australia (Figure 10). South Africa did not play in any T20 matches in 2017, unlike other countries, and therefore had fewer opportunities for their batters to achieve high run totals. Eleven batters, six from England, scored more than 50 runs in a T20 match against South Africa and, similar to that of an ODI century scored against South Africa, a high number of boundaries were scored (Appendix D). This data ranged from 2009 to 2016 and thus may have changed; however, these results suggest that South African bowlers and fielders are not being positioned correctly on the field.

The level of South African women's cricket is improving with the slow increase in exposure. In 2014, a total of 14 players were provided with full-time playing contracts, which is still quite low considering that this is the total number across the entire country; however, it is heading in the right direction. Media coverage, however, is still lacking, with many of the women's matches that are played in South Africa not being televised or advertised to the same extent as those of their male counterparts

5.8 Simulated batting protocol (W-BATEX)

The protocol was designed based on the time-motion data from this study. The protocol has four different stages completed within a total of 20 overs, which is different to the six stages and 50 overs of the BATEX© protocol. A ball is delivered every 32 seconds as opposed to 44 seconds in the men's protocol. Furthermore, the female batter is only given 60 seconds between each over to recover, which is 20 seconds less than the male batters receive when completing the BATEX© protocol. This results in each over lasting 3 minutes and 47 seconds, and the total duration of the protocol is 1 hour and 5 minutes and 40 seconds. The difference in the number of stages and overs can, however, be explained as Houghton *et al.* (2011) increased the overall duration of his protocol to consider the partnership totals. The partnership of female batters was not investigated in this study since the only matches available were ones that were televised, thus the various camera angles required to analyse the runs between the wickets by both batters were unavailable. The simulated protocol for female batters, therefore, does not include partnership totals. However, to simulate the overall demands of scoring a century with another batter at the crease, the protocol should be done by two batters at a time. This would involve the batters doing the protocol simultaneously, and would require each batter to complete each over directly after each other i.e. batter one would complete over one followed by batter two completing over one.

The total number of runs scored in this protocol is 102 off 120 deliveries. This is seven deliveries greater than the mean recorded in the century breakdown (Table 11). However, to accommodate the number of dot balls, these extra deliveries were added. No sixes were included in the protocol as the batter would not run between the wickets. Similar to that of the BATEX© protocol, batters run at maximal speed in stages two and four and at a self-selected pace in stages one and three. The different running requirements in the stages replicate that of an actual match scenario, representing the low and high-risk scenarios. These changes in intensity may aid developing players who do not have the experience of combining the skill, concentration, and fitness demands required for a prolonged batting innings (Houghton *et al*, 2011). Unfortunately, the running requirements of each stage are based on the BATEX© protocol and may not be an accurate representation of scoring a century in women's cricket. Since the only women's matches available were ones that were televised, and the various camera angles required to analyse the runs between the wickets was therefore unavailable. However, the number of runs per stage is based on the data from this study (Table 16).

5.9 Limitations

Although every effort was made to control any extraneous variables that may have affected the investigation, there were several limitations. These should, therefore, be considered when examining the findings of the study:

There was a very limited sample size due to the availability of televised matches. This resulted in only 10 matches being analysed (i.e. four ODI and six T20 matches). A larger sample size would clarify the differences between the male and female motion demands. There were only T20 matches available up until 2016, as there were no televised matches in 2017. The motion demands may, therefore, have changed.

The lack of software available resulted in the motion demands being recorded with a stop-watch instead of utilising GPS. This, therefore, did not allow the researcher to obtain the durations of the periods of walking, jogging and sprinting of the players during a match. The only matches available were ones that were televised, thus the various camera angles required to analyse the runs between the wickets by the batters were unavailable. We could, therefore, not compare these findings with the findings of Duffield and Drinkwater (2008) and Peterson *et al*. (2009).

The protocol design had various limitations, mainly due to the lack of available televised matches, the remaining information needed was therefore taken from CricInfo. In order to increase the validity of the protocol, more televised matches need to be analysed.

CHAPTER VI

Conclusions and recommendations

6.1 Conclusion

The first objective of this study was to determine and quantify the motion demands of ODI and T20 cricket matches. The results of this indicate that the women's game has different demands, in terms of the time-motion analyses, when compared to the men's game in both the ODI and T20 formats. Differences can be seen within the women's game depending on the country that is playing, which is especially evident with regards to South Africa. The second objective was to determine the breakdown of a century scored in ODI matches and the breakdown of a half century scored in T20 matches. It was determined that again, these differed to the male century breakdown and thus indicated that female batters cannot utilise the BATEX© protocol effectively and that a specific protocol designed for the female batter is required. The third and final objective was to establish a simulated batting training protocol to allow researchers to have a greater understanding of the physical demands placed on the female batter. A protocol was designed based on the results of the first two objectives the validity and reliability of which needs to be tested. The current batting simulation (W-BATEX) may, however, be useful for training purposes as the stages of the batting simulation may be used independently or in any desired combination to appropriately simulate match-day demands.

Overall, it can be concluded that the way in which women score during batting in ODIs and T20 are different to men and different between countries.

6.2 Recommendations for future research

With regards to future studies seeking to examine the motion demands of women's cricket in all formats, the following recommendations should be considered:

1. The number of studies focusing solely on women's cricket is lacking, therefore future studies should first obtain more research on all aspects of women's cricket such as perceptual, injury risk, biomechanical, physiological and training load. This will provide a better representation of the demands of cricket on female batters and bowlers.

2. Due to the limited equipment available for use in this study, it was not possible to obtain motion demands with respect to sprinting, jogging, walking etc. and therefore this study could not be compared to studies by Duffield and Drinkwater (2008). Future studies should utilise GPS or similar software to obtain these data and better quantify the motion demands of women's cricket.

3. To achieve a more accurate representation of the motion demands of the women's game, it is recommended that a greater sample of ODI and T20 matches be ascertained and that tests matches be included as well.

4. To ascertain accurate partnership totals of female batters when scoring a century. This should be done by viewing ODI matches in which a century is scored. This would provide a better understanding of the total demands placed on a female batter when scoring a century.

5. To ascertain whether the protocol is valid and reliable, it is recommended that the protocol is tested in a laboratory setting before being utilised in any training programmes.

6. Once the protocol has been validated, it is recommended that the delivery time and time between overs be adjusted according to the specific country. This is will allow better preparation for the batter against a specific opposition.

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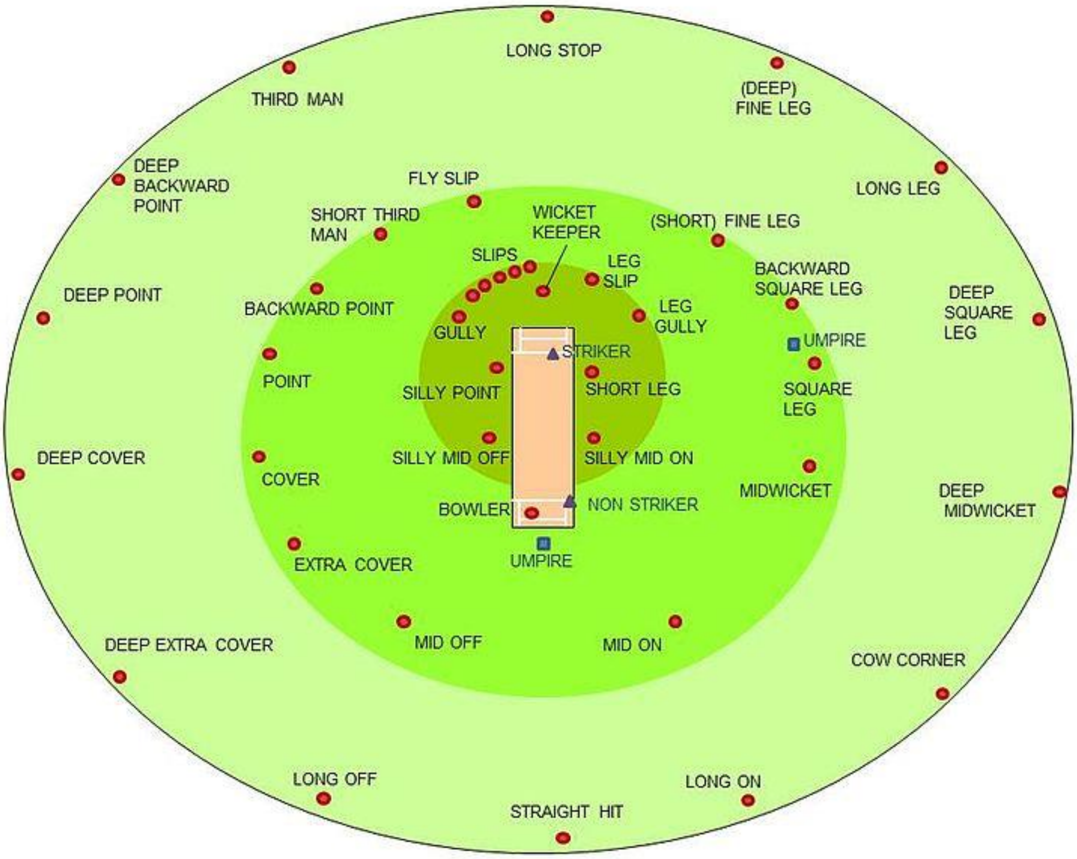
Appendices

7.1 Appendix A: Fielding placements



Taken from:

https://en.wikipedia.org/wiki/Fielding_(cricket)#/media/File:Cricketfieldingpositions.jpg on 11th of February 2018

7.2 Appendix B: Breakdown of centuries scored against South Africa

Country	Against	Team Total	Runs	Duration	Balls Faced	Strike Rate	1s	2s	3s	4s	6s	Dot Balls
West Indies	South Africa	182	108	169	117	92.30	30	9	1	11	2	64
England	South Africa	297	125	169	127	98.42	48	13	1	12	0	53
England	South Africa	297	107	128	102	104.90	37	5	0	15	0	45
England	South Africa	315	138	165	139	99.28	44	3	0	22	0	70
Australia	South Africa	278	134	-	122	109.83	42	6	0	20	0	54
	Mean	**273.8**	**122.4**	**157.75**	**121.4**	**100.95**	**40.2**	**7.2**	**0.4**	**16**	**0.4**	**57.2**

7.3 Appendix C: Breakdown of centuries scored by South Africa

Country	Team Total	Runs	Duration	Balls Faced	Strike Rate	1s	2s	3s	4s	6s	Dot Balls
South Africa	237	100	134	105	95,23	43	6	2	10	0	44
South Africa	272	116	122	99	117,17	40	9	2	13	0	35
South Africa	260	105	143	125	84.00	28	8	2	14	0	73
South Africa	173	102	-	89	114,60	29	4	0	6	7	43
South Africa	337	149	179	149	100.00	61	10	0	17	0	61
Mean	**255.8**	**114.4**	**144.5**	**113.4**	**102.20**	**40.2**	**7.4**	**1.2**	**12**	**1.4**	**51.2**

7.4 Appendix D: Breakdown of T20 run scored against South Africa

Country	Against	Team Total	Runs	Duration	Balls Faced	Strike Rate	1s	2s	3s	4s	6s	Dot Balls
New Zealand	South Africa	151	59	59	48	128.26	16	1	1	5	3	22
Sri Lanka	South Africa	119	63	74	62	101.61	31	3	0	5	1	22
Sri Lanka	South Africa	109	50	42	34	147.05	14	1	0	7	1	11
England	South Africa	91	62	48	54	114.81	13	3	1	10	0	27
England	South Africa	141	75	70	61	122.95	27	2	0	11	0	21
England	South Africa	126	74	59	60	123.33	22	5	0	9	1	23
England	South Africa	147	74	63	51	145.09	24	3	0	11	0	13
England	South Africa	156	66	66	52	126.92	25	5	0	8	0	14
England	South Africa	133	60	49	40	150.00	16	2	0	10	0	12
West Indies	South Africa	143	63	56	53	118.86	23	3	0	7	1	19
Sri Lanka	South Africa	114	52	44	49	106.12	24	1	0	5	1	18
	Mean	**130**	**63.45**	**57.27**	**51.27**	**125.91**	**21.36**	**2.64**	**0.18**	**8**	**0.73**	**18.36**

7.5 Appendix E: Breakdown of T20 run scores by South Africa

Country	Team Total	Runs	Duration	Balls Faced	Strike Rate	1s	2s	3s	4s	6s	Dot Balls
South Africa	118	50	51	52	96.15	30	2	0	4	0	16
South Africa	109	52	50	52	100.00	22	5	0	5	0	20
South Africa	123	51	68	54	94.44	21	5	0	5	0	23
South Africa	119	50	57	63	79.36	12	9	0	2	2	38
South Africa	116	51	62	47	108.51	23	4	0	5	0	15
South Africa	136	70	-	48	102.94	26	2	0	7	2	11
South Africa	107	67	70	80	83.75	25	5	0	8	0	42
South Africa	132	52	51	49	106.12	22	1	0	7	0	19
South Africa	145	63	41	43	146.51	15	4	0	7	2	15
South Africa	131	69	63	61	113.11	25	0	0	8	2	26
South Africa	144	55	61	41	134.14	14	7	1	6	0	13
Mean	**125.45**	**57.27**	**57.4**	**53.64**	**105.91**	**21.36**	**4**	**0.09**	**5.82**	**0.73**	**21.64**