Workloads of Semi-professional Cricket Players, Participating in Three Different Match Formats over a Competitive Season

by

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DECLARATION

By submitting this dissertation electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification

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SUMMARY

Limited data exists on the differences in load between match formats and between disciplines in cricket. Therefore, the primary aim of this study was to monitor match loads, but specifically to determine discipline specific as well as format specific match loads.

Eleven semi-professional cricketers (age: 22.36 ± 2.80; BMI 24.79 ± 2.14) volunteered to take part in the study which was conducted over one season, spanning six months.

Match load was determined using Global Positioning System (GPS) units and heart rate monitors. Fatigue and well-being was monitored three times during the season (Baseline, mid-season and end of season) using the Training Distress Scale (TDS). Internal response to training was determined three times during the season (Baseline, mid-season and end of season) using biomarker (Cortisol, Testosterone and Dehydroepiandrosterone) concentration.

There were no overall differences between the match formats in terms of intensity. Three-day matches did however result in a greater volume in terms of distance covered during an innings.

Fast bowlers experienced the most load across all the three match formats. They covered greater distances by sprinting, compared to medium-paced bowlers, batsmen and all-rounders whom are spin bowlers. They also recorded higher total body load scores compared to batsmen and all-rounders whom are spin bowlers.

It was found that cortisol concentration decreased significantly from baseline to the middle of the season testing session. The concentration then increased significantly from the middle point to the end of the season. The increased cortisol concentration during the second half of the season could demonstrate the accumulated fatigue resulting from the loads over the season.

The TDS scores decreased steadily throughout the season. Load that players experience can be physical as well as emotional/psychological. The TDS scores in this study mirrored the results of the matches.

Key words: Workloads; Semi-professional Cricket Players; Match Formats

OPSOMMING

Beperkte data is beskikbaar oor die verskille in ladings tussen die verskillende wedstrydformate (T20, 50 beurte en drie-dag) en rolle in krieket. Die hoofdoel van die studie was om die wedstrydladings, en meer spesifiek, die verskille tussen die posisies en wedstrydspesifieke ladings te monitor.

Elf semi-professionele krieketspelers (ouderdom: 22.36 ± 2.80; BMI 24.79 ± 2.14) het vrywillig aan die studie deelgeneem wat oor een seisoen van ses maande geduur het.

Wedstrydlading is met behulp van Globale posisioneringstelsel (GPS) eenhede en hartspoedmonitors bepaal. Vermoeienis en welwees is driekeer gedurende die seisoen gemonitor (basislyn, mid-seisoen en einde van die seisoen) met behulp van die oefen-distresskaal (TDS). Interne response op die oefening is driekeer deur die seisoen (basislyn, mid-seisoen en einde van die seisoen) bepaal deur biomerkerkonsentrasies (Kortisol, Testosteroon en Dehydroepiandrosterone). Daar was geen verskille tussen die verskillende formate in terme van intensiteit nie. Drie-dagwedstryde het groter volumes getoon in terme van die afstand wat gedurende ‘n beurt afgelê is.

Snelboulers het die grootste lading ondergaan in al drie spel formate. Hulle het die grootste afstande gedek een ook die hoogste totale liggaamsladingtellings getoon.

Die kortisolkonsentrasies het beduidend afgeneem vanaf basislyn na die mid-seisoen toetsgeleentheid. Die kortisolkonsentrasie het weer toegeneem vanaf mid-seisoen na die einde van die seisoen. Dit is moontlik dat die toename in kortisol na die einde van die seisoen ‘n aanduiding van ‘n akkumulering in vermoeienis kan wees as gevolg van die lading gedurende die seisoen.

Die TDS tellings het geleidelik deur die seiesoen afgeneem. Die ladings wat spelers ervaar, kan dus fisiek, sowel as emosioneel/sielkundig wees. In hierdie studie het die TDS tellings ooreengestem met die uitslae van die wedstryde.

Sleutelwoorde: Werkladings; Semi-professionele Krieketspelers; Wedstrydformaat

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LIST OF ABBREVIATIONS

T20	:	Twenty20
GPS	:	Global Positioning System
ICC	:	International Cricket Council
ODI	:	One Day International (s)
ECB	:	England and Wales Cricket Board
B & H	:	Benson and Hedges
GAS	:	General adaptation syndrome
OTS	:	Overtraining Syndrome
TDS	:	Training distress scale
HIT	:	High intensity interval training
DHEA	:	Dehydroepiandrosterone
HPA	:	Hypothalamic-pituitary-adrenal
T	:	Testosterone
C	:	Cortisol
CMJ	:	Counter-movement jump
[ ]	:	Concentration
Hz	:	Hertz

m/s	:	Metres per second
km/h	:	Kilometres per hour
CEO	:	Chief Executive Officer
N	:	Sample size
Cm	:	Centimetre (s)
HRM	:	Heart rate monitor
ULOQ	:	Upper limit of quantification
LLOQ	:	Lower limit of quantification
QC	:	Quality control
TMBE	:	Tert-methyl-butyl ether
rpm	:	Revolutions per minute
°C	:	Degrees Celsius
ul	:	Microlitre
ANOVA	:	Analysis of variance
SD	:	Standard deviation
kg	:	Kilogram (s)
BMI	:	Body mass index
Kg/m^2	:	Kilograms per metre squared
Vmax	:	Maximum velocity

%	:	Percentage
HR	:	Heart rate
mmol/l	:	Millimole per litre
TT	:	Total Testosterone
nmol/l	:	Nanomole per litre
vs.	:	Versus

CHAPTER ONE

INTRODUCTION

Although cricket is one of the oldest organised sports, there is a relative lack of scientific research of the sport and it's players. There are, for example, very few studies of the physiological demands of cricket or of the specific physiological, biochemical or anthropometric attributes of top-class cricketers. International cricket is undergoing a phase of rapid changes as it competes to attract a more global audience. As a result, modern international cricketers are now exposed to greater physical and psychological demands. These expanded demands include more five- and one- day matches per season, a longer season without a real winter break, more frequent tours and less time spent at home. (Noakes & Durandt., 2000). The introduction of T20 cricket has been the latest addition to the formats. The shortened format was initially introduced to bolster crowds for the domestic game, and was not intended to be played internationally, but the first T20 International took place on 17 February 2005. Australia defeated New Zealand, and the first tournament was played two years later, with the introduction of the ICC World T20. There remain limits on how many T20 Internationals a team can play each year, in order to protect Test cricket and One Day Internationals. (Twenty20 International, 2016).

The demands on players has steadily increased over the years. The introduction of T20 tournaments such as the Indian- and Caribbean- Premier League, Big Bash and Pakistan Super League, has resulted in some players having very busy schedules. Cricket today demands greater physical effort from players at vital stages during their careers. It is the duty of the players, coaches, medical support team, and administrators to put in place measures to ensure that unnecessary injuries do not prevent players from reaching their full potential (Stretch, R.A., 2003).

First utilized for athlete tracking in 1997, GPS technology is now increasingly used in team sport settings to provide sports scientists, coaches and trainers with comprehensive and real-time analysis of on-field player performance during competition or training (Cummins *et al*., 2013).

There are a limited amount of studies observing training and match loads in cricket, especially over an entire season. Most studies deal with injury prevalence and loads over a short period of time. A few studies have compared the match loads of fast bowlers and non-fast bowlers, but few studies have included the other disciplines such as batsmen, spin bowlers, all-rounders and wicket keepers.

This study seeks to address unanswered questions in terms of differences between formats and player disciplines over an entire season.

A. Aim of the Study

The aim of the current study was to monitor match loads, as well as recovery and fatigue, of players (n=11) from a semi-professional cricket team over a competitive season

B. Research Objectives of the Study

The specific objectives of the study were to:

1. Determine loads in high-level cricket players over a competitive cricket season.
2. Determine differences in match format loads over a competitive cricket season.
3. Determine position-specific loads of batsmen, bowlers, and all-rounders over a competitive cricket season.
4. Determine match format specific loads of batsmen, bowlers, and all-rounders over a competitive cricket season.
5. Determine the cortisol responses in high-level cricket players over a competitive season.

6. Determine the testosterone responses in high-level cricket players over a competitive season.
7. Determine the dehydroepiandrosterone (DHEA) responses in high-level cricket players over a competitive season.
8. Determine the differences in cortisol responses between batsmen, bowlers, and all-rounders over a competitive season.
9. Determine the differences in testosterone responses between batsmen, bowlers, and all-rounders over a competitive season.
10. Determine the differences in dehydroepiandrosterone (DHEA) responses between batsmen, bowlers, and all-rounders over a competitive season.

C. Outline of the Thesis

Chapter Two consists of the theoretical context of the current study. The chapter covers relevant literature which includes studies on cricket, monitoring of athletes and GPS. Chapter Three outlines the methodology used for the capturing of the data. The results of this study are presented in Chapter Four. Chapter Five consists of a discussion of the main findings and provides a conclusion, limitations of the study, and recommendations for future research.

CHAPTER TWO

THEORETICAL CONTEXT

A. INTRODUCTION

Generally there is a lack of studies on movement profiles of cricket players, as well as training and match loads in cricket (McNamara *et al.*, 2013). Accurate assessment of the movement profiles of athletes, during training and match-play, can assist in the development of specific conditioning activities and recovery strategies. Accordingly, the use of Global Positioning Systems (GPS) technology has been used to measure movement patterns; specifically distance covered and speed of movement, in many intermittent-sprint sports (Duffield *et al.*, 2009).

This chapter provides a theoretical background to the study. It consists of an explanation of cricket, the history of the sport, as well as the three different formats which have been developed. The mechanics of GPS and its increasing role in athlete tracking and sport is documented. The tracking of athletes involves the determination of internal and external training loads, as well as the monitoring of fatigue and recovery. The variables associated with determining such loads and the monitoring of recovery and fatigue are discussed. The trend of increasing loads on athletes, and the resulting importance of athlete monitoring, is mentioned.

B. CRICKET

The game of cricket

Cricket is a bat and ball sport played between two teams, each comprising of 11 players. Each team is made up of batsmen, bowlers and fielders. A player who is efficient at both bowling and batting is known as an all-rounder. Four-day and Test matches comprise of two batting innings per team over a period of four days and five days respectively. The field is oval with a rectangular area in the middle, known as the pitch. The pitch is 22 yards (20.12 metres) long and 10 feet (3.04 metres) wide. Two sets of three sticks, called wickets, are set in the ground at each end of the pitch. Across the top of each wicket lie horizontal, wooden pieces called bails. The bowlers, delivering the ball with a straight arm, try to hit the wicket with the ball so that the bails are dislodged. This is one of several ways that the batsman can be dismissed. A bowler delivers six balls at one wicket to complete an ‘over’. The batting team defends its wicket. Only two batsmen take part in the match at any given time. Once a batsman is dismissed, he is replaced by another batsman until 10 batsmen have been dismissed (Longmore, 2015).

According to Longmore (2015), cricket is believed to have begun possibly as early as the 13th century as a game in which country boys bowled at a tree stump or at the hurdle gate into a sheep pen. The earliest reference to an 11-a-side match, played in Sussex for a stake of 50 guineas, dates from 1697. In 1709, Kent met Surrey in the first recorded inter-county match at Dartford. It is probable that about this time a code of laws (rules) existed for the conduct of the game, although the earliest known version of such rules is dated 1744. In 1907, South Africa first played Test matches in England and also took on Australia.

The governing body of world cricket, now known as the International Cricket Council (ICC), currently has 106 member countries.

Table 2.1. Development of the International Cricket Council, as described by the ICC organisation

Date	Event	Details
1907	Imperial Cricket Board established	Govern matches between England, Australia and South Africa
1926	Meeting of Imperial Cricket Conference	West Indies, New Zealand and India became Test playing nations.
1952	Pakistan admitted to ICC	
1961	South Africa no longer eligible for ICC membership	Due to withdrawal from Commonwealth
1964	Expansion of ICC to include non-Test playing countries.	
1965	ICC changed its name to International Cricket Conference	
1974	Argentina, Israel and Singapore added as new associate members	
1975	World Cup (60 overs) in England	Participants: The six test playing nations, East Africa and Sri Lanka

1976	West Africa added as new associate member	
1977	Bangladesh added as new associate member	
1978	World Series Cricket formed by Kerry Packer. Papua-New Guinea joined as an Associate, but South Africa's application to rejoin was rejected.	World Series Cricket attracted many of world's best players, threatening to de-rail test cricket
1981	Sri Lanka raised to full membership	
1989	South Africa banned from Test cricket	
	Named changed to International Cricket Council	
1991	South Africa re-admitted as full Members and the ban on players who had sporting connections with South Africa was revoked. Zimbabwe admitted as a full Member	

1993	From the time of South Africa's withdrawal, England and Australia had enjoyed the status of 'Foundation members,' and this effectively meant that little could be achieved unless the two countries concurred. However, with the implementation of the new Regulations, all this changed. England and Australia lost their special privilege, all Test playing countries now being of equal standing.	
2005	ICC left it's base at Lord's to set up new headquarters in Dubai	

The ICC continues to face such matters as match-fixing, player conduct, the use of floodlights and the challenge of balancing the three formats of the game. As it addresses these issues, the ICC strives to remain true to the purpose enshrined in its mission statement that 'As a leading global sport, cricket will captivate and inspire people of every age, gender, background and ability while building bridges between continents, countries and communities' (History of the International Cricket Council, 2015).

Cricket is being played predominantly in the Commonwealth countries, with 10 national teams competing in test cricket, 12 in one day internationals (ODIs) and 15 in the T20 format. As with some other sports, the original format of the game has been changed and /or adapted over the years.

Due to the focus of the current study, the different match formats that have been developed, will be explained briefly in the next section.

Match formats

The three formats of the game that currently exist, are T20, one day internationals (ODIs) and test matches. T20 matches consist of 20 overs per innings. ODI's consist of 50 overs per innings and test matches consist of four innings, two per team, spanning over five days. Test matches are played at International level, whereas this study focussed on three-day cricket at provincial level. T20 is one of the latest forms of cricket, with an origin that can be traced back to the late 1990s and early 2000s. As a shortened format of cricket, T20 took birth in the form of an idea, which was discussed by the England and Wales Cricket Board (ECB) in 1998 and then again, in 2001. However, the idea only started taking a concrete shape in 2001. The Benson & Hedges Cup (B&H Cup) was coming to an end. The ECB felt the need for another one-day competition, as a replacement. The Benson & Hedges Cup was a one-day cricket competition for first-class counties in England and Wales that was held from 1972 to 2002, one of cricket's longest sponsorship deals. Established in the wake of the success of the end-of-season 60-over competition and the resulting Sunday league, the B&H was the third major one-day competition established in England and Wales after the Sunday League and the Gillette Cup (Benson & Hedges Cup, 2015). In its latter years it increasingly came under fire, critics arguing it was one competition too many and also attacking it for its rather clumsy system of zonal matches. In its defence, the B&H Cup provided good income for the counties and some decent early-season entertainment (A brief history of the Benson & Hedges Cup, 2015). The B&H Cup's later years coincided with increasing concern about the quantity of one-day cricket in England and Wales. A ban on tobacco advertising deprived the cup of its sponsor and it was wound up in 2002 in favour of the Twenty20 Cup, first held the following year (Benson & Hedges Cup, 2015).

It was Stuart Robertson, the marketing manager of the ECB, who came up with the proposal for a 40-over game, with 20 overs per innings. He presented the concept formally in 2001, to the county chairmen. Apart from filling the space that would be emptied by culmination of B&H Cup, the new form of cricket also looked to be the perfect way to boost the game's popularity. It seemed to be the best option to win back the interest of the younger generation and thus, the declining sponsorship (Twenty20 Origin, 2015).

Table 2.2 Current match formats played at international level

Match format	Description
Twenty20 (T20)	T20 matches consist of two innings' of 20 overs. A match duration is usually four hours. T20 matches are usually played before the ODI and Test match series', usually in a series of two or three matches.
One day international (ODI)	Consists of two innings' of 50 overs each. A match duration is usually seven hours. Usually played in a series of three, five or seven matches. ODIs are sometimes played among three teams, in what is termed a triangular series.
Test match	Consists of four innings, two batting and two bowling innings' per team. Played over five consecutive days. Each day consists of 90 overs (weather and light permitting) played over eight hours. Usually played in a series of two, three, four or five matches.

Marked differences in movement patterns were evident between disciplines and game formats, with fast bowlers undertaking the greatest workload. Fast bowlers sprinted twice as often, covered over three times the distance sprinting, with much smaller work-to-recovery ratios. Fast bowlers during multi-day matches covered 22.6±4.0 km (mean±s) total distance in a day (1.4±0.9 km in sprinting). In comparison, wicketkeepers rarely sprinted, despite still covering a daily total distance of 16.6±2.1 km (Petersen *et al*., 2010). T20 cricket, which is played over a duration of approximately three hours, has grown in popularity in recent years, and its proliferation has changed the emphasis of certain physical requirements for players (Petersen *et al*., 2010; 2011).

Overall, One Day and T20 cricket required 50 to 100% more sprinting per hour than multi-day matches. However, multi-day cricket's longer duration resulted in 16–130% more sprinting per day. In summary, the shorter formats (T20 and One Day) are more intensive per unit of time, but multi-day cricket has a greater overall physical load (Petersen *et al*., 2010).

Fielders are required to cover large distances in a day (up to 15.5 km), but more than 77% of these distances are covered by walking. Stationary and walking activity represented 94.2±2.4% of match time (Rudkin & O'Donoghue, 2008).

Petersen *et al*. (2010) identified differences in match intensity between fast bowlers and non-fast bowlers; fast bowlers covered significantly more distance and at greater intensities than non-fast bowlers. In the same study it was found that game format also influenced the load and intensity of fast bowlers and non-fast bowlers, with 20-over matches resulting in higher average intensities than 50-over and multiday cricket. Previous research has found that while one-day cricket formats had greater intensities, multiday cricket involved greater overall load. The activity profiles of competitive match play and cricket training activities typically used to develop skill and physical fitness have also been investigated. Petersen *et al.* (2010) found higher heart rate and blood lactate concentration during conditioning training than competition. Few other studies have investigated the physical demands of cricket, with the majority of them limited to the acute responses to cricket-related tasks reporting heart rate, blood lactate concentration and hydration status during bowling spells.

During a batting innings, a similar fractional predominance of time spent in low-intensity activity (standing and walking) between Test and one-day matches (94 and 96% respectively) was observed, with no differences in the duration of striding or sprinting. In summary, Test and one-day innings are characterized by much low-intensity activity and patterns of high-intensity activity similar to many repeat-sprint team sports and greater recovery breaks during longer matches (Duffield & Drinkwater, 2008).

A one-day world cup, as well as a T20 world cup, is played every 4 years. The last Cricket World Cup, held in 2015, was won by Australia. The last World T20, held in 2016, was won by the West Indies.

Table 2.3 Current match formats played in South Africa

Match format	**Description**
Twenty20 (T20)	T20 matches are played between the six franchise (professional) teams as well as between the 14 semi-professional teams
50 over match	Fifty over matches are played between the six franchise (professional) teams as well as between the 14 semi-professional teams.
Multi-day matches	Consists of four innings, two batting and two bowling innings' per team. At franchise (professional) level, these matches are comprised of four days, whereas at the semi-professional level, they are comprised of three days.

The game of cricket has undergone many changes over the years. Even though it has grown to become a popular sport internationally, not many studies have compared the game demands of the different formats. The focus of the current study will therefore be on the game demands placed on players by the three different formats of the sport.

C. GLOBAL POSITIONING SYSTEMS (GPS)

Mechanics of GPS

Global positioning systems (GPS) are based on the work done by Isisdor Rabi, the 1944 Nobel laureate in physics. The magnetic resonance method was developed through precise measures on the hydrogen atom. The development of the nuclear magnetic resonance method lead directly to the creation of atomic clocks, the precise timepieces that form the basis of satellite navigation. The precise measurement of time from the atomic clock allows for the calculation of the length of time it takes a radio signal to travel from the satellite to the GPS receiver on earth. Thus, the distance from the satellite to the receiver can be derived, and, if at least four satellites are in communication with that receiver, accurate location of the receiver can be triangulated. Once the position is known, the displacement over a given epoch can be used to calculate velocity of movement (Aughey, 2011).

GPS in sport

During the past decade, time-motion analysis systems such as video recording, hand notation and computer digitizing have been used to objectively assess human locomotion for determining physiological measures. In addition, these systems have been used to improve sport performance. Unfortunately, many logistical issues exist including questionable validity, the labour extensive nature for collecting such data and a requirement of manual hand-notation techniques. Another concern is the failure of these systems to provide real-time information on the context of human locomotion. For example, athlete position, movement displacement, velocity and acceleration of their movements, which are considered vital quantitative information for athletes and teams, are often not examined. One solution may reside in the use of global positioning systems (GPS) and accelerometer technology, two instruments often used in the sport and physical activity realm (Dellaserra *et al.*, 2014).

The development of GPS in 1990 has enabled collection of real-time data on human locomotion to examine sport performance in a more convenient, efficient and precise manner. GPS studies have evolved from assessing steady state movements for examining energy expenditure to assessing human locomotion within the context of sport. Currently, two types of GPS networks exist, differential and non-differential. Differential GPS was primarily used in earlier studies to determine speed, position and distance measurements of orienteering athletes. Non-differential GPS units have several advantages over differential GPS which include decreased cost, lighter and smaller design and a simplified data analysis procedure (Dellaserra *et al*., 2014).

Dellaserra *et al*. (2014) gave an elaborate explanation on the combined use of GPS and other monitoring devices. GPS units are often combined with accelerometers to determine objective recordings of physical activities conducted during various times of the day. Accelerometers, or devices that measure physical activity in three planes, have previously been used to examine physical activity levels as they correspond to public health. Accelerometers use “cut points” to classify individuals from “low activity” to “high activity” levels and they evaluate daily activities of living from data recordings of linear movement on several axes. The most common types of accelerometers are peizoresistive, piezoelectric and differential capacitive. Differential capacitive are used most widely used in sport and physical activity settings due to their ability to classify posture and movement, estimate energy expenditure and analyze gait and balance control. The combination of GPS, accelerometer and heart rate technology, which is called ‘integrated technology (IT)' by the aforementioned authors, allows for a greater understanding of the energy cost and specificity of movement patterns in controlled situations. IT was first developed in 2003 with the SPI-10, and recent models include the MinimaxX OptimEye, SPI Pro and SPI Elite. The MinimaxX series, the most commonly used IT models in training and research have examined numerous sports, including Australian Rules football, soccer, cricket, field hockey and team sport simulations. The majority of studies utilizing IT have targeted physical activity among the general population (e.g., adults, children, senior citizens). However, during the last five years, research has expanded to include amateur and elite athletic populations. The recent use of IT in sport settings presents the capability to overcome limitations of time-motion analysis systems. These sport-specific units can measure various locomotor categories (e.g., sprinting, jogging), distance travelled and length and distance of sprints done by athletes in specific sports. The use of IT has been examined in team-based field sports, including soccer, field hockey, Australian Rules football, rugby and cricket. While this method of study is still emerging, using IT in team sport settings has been deemed reliable and valid, requires minimal human involvement during data collection due to its non-invasive nature and produces rapid data collection and analysis compared to video-based analysis.

First utilized for athlete tracking in 1997, GPS technology is now increasingly used in team sport settings to provide sports scientists, coaches and trainers with comprehensive and real-time analysis of on-field player performance during competition or training (Cummins *et al*., 2013)

The re-test reliability between GPS devices is fairly consistent. Waldron *et al.* (2011) examined the test-re-test reliability between GPS units, finding random errors between two tests ranging from 0.56 to 1.64 $km \cdot h^{-1}$ and small mean biases (-0.01 to -0.14 $km \cdot h^{-1}$) for all sprint intervals (Cummins *et al*., 2013)

GPS in cricket

By measuring player movements, GPS can be used to objectively quantify levels of exertion and physical stress on individual athletes, examine competition performances, assess different positional workloads, establish training intensities and monitor changes in player physiologic demands. Player movement patterns and activity profiles (external loads) can be used in addition to tactical information and physiological responses (internal load) to characterize competitive match play. From its introduction, GPS was used to measure basic components of player movement patterns, speed and distance travelled, and the number of accelerations and decelerations. The integration of GPS with a tri-axial accelerometer enables the capture of information on work rate patterns and physical loads. The tri-axial accelerometer measures a composite vector magnitude (expressed as a G-force) by recording the sum of accelerations measured in three axes (X, Y, and Z planes). In addition, the number and intensity of physical contacts and collisions between athletes and objects or surfaces can be quantified by body load and impact measures. Body load (measured as G-force) is the collation of all forces imposed on an athlete, including acceleration/deceleration, related changes of direction and impacts from both the player-to-player collision and contact with the ground (foot strikes and falls). The first attempts were made to validate GPS for field sport applications in 2006 (Aughey, 2011).

Studies have been conducted in which GPS units have been used to quantify training and match demands across a season. They explored the relationship between training and game demand on an individual level as well as exploring the relative demand on different fielding positions (Neville *et al*., 2012). 10 Hz GPS units are acceptable for detecting the smallest worthwhile change during constant velocity and acceleration/deceleration up to 8m.s. These units provide an acceptable accuracy and reliability for determining instantaneous velocity for all phases of straight-line running (Varley *et al*., 2011). The distance data was found to be highly accurate and only slightly underestimated by the GPS devices. Furthermore, high intra- and inter-device reliability was observed. Accuracy improved with increased distance, and the mean SEM of 10.9% when running 15 m was reduced by half over 30 m. Using similar statistics and methodology, Petersen *et al*. (2009) found SEM values of between 5% and 24% for MinimaxX devices and between 3% and 11% with SPI-Pro devices, both at a sampling frequency of 5 Hz. Here, only one device (number 1) produced values above 6% in the 15 m test, while another device (number 2) did so for runs of 30 m. They concluded that the increase in sampling frequency led to increased accuracy of the devices. As regards intra-device reliability, high values were obtained in all cases, and increased when used for distances greater than 30 m (Castellano *et al*., 2011).

As shown in the literature, GPS gained popularity in sport due to the benefits mentioned in the previous section. However, not much research has been conducted in cricket and more specifically in the area of the different formats. The current study aimed to address this knowledge gap.

D. MONITORING ATHLETES

Monitoring workloads in athletes

Workloads can be classified as either internal or external. The internal workload represents the physiological stress imposed upon the athlete in response to the training stimulus (e.g. perceptual rating of fatigue, heart rate). Quantification of the physical training stimulus detached from the internal response of athletes indicates the external workload (e.g. session duration, distance travelled, running speed, acceleration) (Scanlan *et al*., 2014).

Theory suggests that internal training loads may be most appropriate for monitoring training (i.e., the load endured by athletes), whereas the external load is generally considered to be important for the prescription and planning of training. Indeed, in a review of aerobic training within soccer players by Impellizzeri and colleagues (2004), it was suggested that although the individual’s physiological response to a training stimulus (internal load) may be a more acute marker of training load, it is the combination of both the external load (quality, quantity, and organization of the training stimulus) and the individual characteristics that make up the complete training process. Therefore, it might be that these two constructs of training provide different information to coaches that can be used to influence decisions about the training process (i.e., external training loads confirm if planned training outcomes are achieved, whereas internal training load measures can be used to determine how players are responding/coping with training). At present, the common methods for quantifying training load in team sports are heart rate (HR) and microtechnology, including global positioning system (GPS) and accelerometers (Borresen *et al*., 2009). The GPS devices are often used to provide feedback on distance travelled, running speeds, and repeated-sprint efforts of players, whereas accelerometers provide further information on the impacts endured by the athletes, giving feedback on the overall body load these impacts generate. It has recently been demonstrated that accelerometers have an acceptable level of technical reliability both within and between devices for measuring physical activity in AF, providing increased practical application within team sports (Impellizzeri *et al*., 2009)

Conditioning coaches monitor the workload or game demands of players in most sports to balance the amount of conditioning and recovery (Petersen *et al*., 2011).

In the 1930s, Hans Selye proposed the general adaptation syndrome (GAS). GAS provides the theoretical basis for training modern athletes (Needham, 2011). According to GAS, physiological and psychological stressors cause systemic reactions. Exposure to stressors cause disruptions to homeostatic equilibrium and produce the GAS Alarm stage. Although the body can respond to future stressors of the same type for a period of time, the body's resistance to other stressors or prolonged exposure to the same stressor is finite. The period of successful stress response is called the Resistance Stage. The Resistance Stage represents a new level of homeostatic equilibrium; however, the Resistance Stage cannot continue indefinitely. At some point, and this point varies from individual to individual, continued resistance is impossible and the Exhaustion Stage is reached. When the Exhaustion Stage is reached, the body's resistance can no longer react to the stressor and the body fails. Athletic training responses parallel GAS. To train, athletes increase the volume or intensity of the activity. These increases in training serve as the stressors to the body. In the language of training, these stressors are called overload and result in an Alarm Stage comprising of a temporary decrement in performance potential. The goal of training is to move the athlete through the Alarm Stage into the Resistance Stage (improved performance potential), by balancing the overload with appropriate recovery. With adequate recovery, the athlete makes the appropriate adaptations to overload and performance increases above baseline. Because of an increase in performance, the athlete can continue to be overloaded at progressively higher levels to cause the optimal amount of adaptation for optimal or peak performance. If recovery is inadequate, the overtraining syndrome (OTS) may occur. OTS is an example of an athlete reaching the Exhaustion Stage when the overload becomes too much for the body to handle. The body's capacity for systemic reaction to the overload becomes exhausted, decreasing the motivation and ability to continue training, and may even result in illness. Given the detrimental consequences of OTS, coaches and sport scientists continually seek strategies for managing overload and recovery.

The use of GPS provides coaches and strength coaches with an objective measure of such training loads and an indication of how to periodize the training.

Increasing demands on cricket players

Based on the amount of days an elite South African cricketer is asked to play in one year, the demands on such cricketers has increased by 280% between 1970 and 2000. Fast bowlers have borne the brunt of this increasingly crowded playing schedule. There has been a dramatic increase in the number of overs bowled in an average season in the last few decades. Therefore, it is certain that only the best physically prepared cricketers will perform better, more consistently, with fewer injuries, and, as a result, will enjoy longer careers. It is for this reason that it is essential to understand the physiological demands of modern cricket, initially for the benefit of individual players and teams, but eventually for the survival and growth of the game itself (Woolmer et al., 2008:528)

> "Australian cricket was galvanized by the systematic, scientific and uncompromisingly exact approach initiated by Bob Simpson in the 1980s; English rugby was revolutionised by in the late 1990s by the methodical approach of coach Clive Woodward, himself a graduate in sport sciences. There is no doubt that the great cricketing nations of the future will be those that adopt similar approaches, as Australia has done with the appointment of John Buchanan, an exercise science graduate, as national coach. Those who choose to remain 'traditionalists' in their approach to the sports sciences will sadly see cricket in their countries fade into the sunset in an increasingly competitive and technologically advanced world" (Woolmer *et al.*, 2008:530).

In the past, cricket in most Commonwealth countries was played solely during the summer months, but its popularity has increased so much that it has lost its 'season' and is now being played throughout the year. Because of the longer season, cricket players are exposed to more demanding schedules, with more time spent training and practising. This increase in workload may be a contributing factor to the increased incidence of injuries noted. Researchers agree that the physical demands of the fast-bowling action can have a damaging effect on the bowlers concerned. Studies done in South Africa have shown bowling to account for 41% of injuries incurred. In a more recent study by the Australian Cricket Board it was reported that fast bowlers at first-class level significantly increased their risk of injury when their bowling workload exceeded more than 20 - 30 overs a week. On average one in six elite Australian fast bowlers was unable to play owing to injury at any given time. It is assumed that the timeous conditioning and monitoring of physical fitness throughout the season will assist in adequately preparing fast bowlers and thus assist in reducing injury. A strong relationship was found between workload and weeks incapacitated (R^2 =0.62, p<0.0005), indicating that excessive bowling workloads influenced the severity of injury to such a degree that there was a linear relationship between bowling workload and weeks a bowler was unable to bowl (Davies *et al*., 2008).

School cricketers experienced a sudden increase in injury incidence during September – this could be attributed to a lack of pre-season training or due to the school holidays. A sudden rise in cricket injuries is also seen during December, when high-intensity cricket is resumed after a relatively inactive period due to year-end examinations (Milsom *et al*., 2007). The same could apply to semi pro cricketers coming back from the mid-season break.

Today elite sportspeople are expected to train longer, harder, and earlier in life to excel in their chosen sport. The modern cricketer is no exception. The demands placed on the cricketer are further increased because of the repetitive nature of the game, often for long periods of time. Thus the demands of cricket, which in the 1970s was regarded as a sport of “moderate injury risk”, have changed, and players are susceptible to a wide variety of injuries at vital stages of the season. Studies of cricket injuries show an increasing incidence, varying from 2.6 to 333/10 000 athlete hours played, with 28.4–71.6% of cricketers sustaining between 1.61 and 1.91 injuries per season.

The high incidence of back injuries in young bowlers is the result of a combination of factors. These include inadequate physical and physiological preparation, postural defects, high physical demands, biomechanical aspects of the bowling technique, escalation in training frequency, duration of bowling spells in matches, and repetitive movements. Injuries tend to occur during specific stages of the season, with the many preseason matches and the concentration of matches toward the end of the season tending to result in an increase in injuries at those times. Cricket today demands greater physical effort from players at vital stages during their careers. It is the duty of the players, coaches, medical support team, and administrators to put in place measures to ensure that unnecessary injuries do not prevent players from reaching their full potential (Stretch, R.A., 2003). Such measures can be the use of GPS technology and the use of other monitoring tools such as the

Training Distress Scale. Together these can play a role in monitoring the athletes workloads and fatigue levels. If fatigue is detected early enough, the player's load can be managed accordingly and injury and/or burnout can be prevented. Fatigue could lead to poor technique, placing the player at further risk of injury

Internal workload can be split further into physiological- and perceptual measures. Physiological measures can be determined by the analysis of biomarker concentrations in the body, as well as by obtaining the heart rate of an athlete.

Perceptual measures can be determined with the use of the 'rate of perceived exertion scale' and the training distress scale.

E. INTERNAL MEASURES TO MONITOR ATHLETES

Heart rate

Heart rate increases during exercise and is directly proportional to the intensity of the training session or match. Therefore, the more intense the training session or match, the higher the heart rate. As mentioned before, heart rate is a component of internal training load. We can measure and monitor the heart rate of an athlete to determine how the body is responding to a particular training session or match situation.

Training distress scale (TDS)

Competitive athletes undertake rigorous training regimes to provide sufficient stimulus for physiological adaptations and performance improvement. At times, however, strain on the body from the physical stress of training combines with psychosocial stressors to exert a negative influence on physical state, mental state and performance capabilities. The inability to continue performing at a customary or expected level may then exacerbate strain on the system. In many instances, performance decrements can be alleviated by temporary reductions in workload and/or active recovery methods. However, work/rest imbalances sometimes lead to a chronically over trained state, where long-term rest is necessary for performance to recover. Early detection of training distress symptoms is, therefore, an important challenge for sport scientists and coaches. Identification of these symptoms permits adjustments to be made to the training programme before short-term “over-reaching” progresses to the longer lasting and more serious “overtraining syndrome”. Numerous physiological variables have been investigated as potential markers of training distress, including metabolic, cardiovascular, immunological, neuromuscular and endocrinological measures. Unfortunately, many of these measures have high intra-individual variability and have shown only weak or inconsistent relationships with training distress (Grove *et al*., 2014).

While numerous physiological and biochemical symptoms have been proposed as potential indicators of overtraining, few have proven to be consistent across different studies involving different athletic groups. Stronger and more consistent relationships have been observed with self-report measures. These measures exhibit reliable dose response relationships with training load and they appear to be sensitive to the symptoms of both short-term and long-term training distress across a range of different sports. Self-report measures have the added advantages of being efficient, inexpensive and non-invasive (Grove *et al*., 2014).

There are a number of ways to determine workload and the impact it has on athletes. The TDS is player- and coach-friendly, cost effective and easy to administer.

Biomarkers

Due to the fact that biomarkers were a prominent aspect of the current study, a separate section on the matter was warranted.

Biomarker measurement can be used as a method of monitoring internal training load. Testosterone and Cortisol are the mostly commonly used biomarkers and are reported on extensively in literature. These hormones shall be discussed in more detail below.

Testosterone

One of the major anabolic hormones in males is testosterone. Physical exercise is known to affect many hormones in the endocrine system and testosterone is no exception. For example, prolonged, steady state endurance exercise (low-moderate intensity physical activity) for extended periods can result in transient non-pathological reductions of testosterone levels, which can last for several hours or days into recovery. Reductions in testosterone, if extensive and prolonged, can compromise a persons' health status. Relative to athletes, these reductions can negatively impact on the adaptation process associated with skeletal muscle, (i.e., myoplasticity) which is fundamental and necessary to the exercise training progression and improvement in performance. In an attempt to improve performance, athletes are known to use many forms of exercise and training techniques in their regimes. High intensity interval training (HIT) has recently gained much attention because of its effectiveness in triggering rapid adaptations in the metabolism of skeletal muscle and increases of maximal oxygen uptake. The influence of such HIT forms of exercise on testosterone status has been studied on a very limited basis with studies thus far reporting equivocal results (Hackney *et al*., 2012).

Cortisol and Dehydroepiandrosterone

Cortisol and dehydroepiandrosterone (DHEA) are stress hormones of the hypothalamic-pituitary-adrenal (HPA) axis. Cortisol is involved in a number of important functions, including responses to stress, energy metabolism, vascular activity and inflammatory and immune responses. DHEA is a precursor to sex hormones; it has been proposed to affect various systems of the body and be anti-ageing and immune enhancing. Cortisol exhibits a marked diurnal rhythm, characterised by a rapid increase in levels upon awakening, peaking at around 30 minutes post awakening and declining to reach the lowest point in the evening, where DHEA has been shown to display a flat pattern of secretion after waking followed by a progressive decline to three hours post awakening with no significant change thereafter.

DHEA has been shown to increase in response to acute exercise in younger adults. Endurance trained young males showed attenuated increases in hormone concentrations in response to exercise compared to resistance-trained individuals (Heaney *et al*., 2011).

The effects of physical exercise on Cortisol and Testosterone concentration levels have been widely documented, with particular reference to the fact that [Cortisol] varies in the opposite direction to [Testosterone], thus showing that physical exercise produces an imbalance between the anabolic hormone of testicular origin and the catabolic hormone of adrenal origin. Many studies have used the T/C ratio to emphasize the variations in these two hormones during the training season. This ratio diminishes when the training load increases, conversely below a certain threshold, it may indicate a state of overtraining. This imbalance may also be caused by a situation of stress resulting from the mental strain or the coupling of mental and physical strain (Elloumi *et al*., 2003). Saliva sampling provides a convenient, non-invasive to determine adrenocortical hormone concentrations. Correlation analysis revealed a moderate but significant relationship between plasma and saliva cortisol ($r = 0.35$, $P<0.02$) and plasma and saliva DHEA ($r = 0.47$, $P<0.001$) during the sub maximal exercise. The results thus suggest that, even under prolonged exercise conditions, non-invasive saliva samples may offer a practical approach to assessing pituitary-adrenal function (Thomasson *et al*., 2010).

McNamara *et al*. (2013) conducted a study in which they investigated the physical preparation and match-play workload of cricketers and described the endocrine, neuromuscular and perceptual fatigue associated with playing the sport. This study investigated key fatigue and workload variables of elite junior fast bowlers and non-fast bowlers during a seven week physical-preparation period and a ten day intensified competition period. Individual workloads were measured via GPS technology, and neuromuscular function (countermovement jump), endocrine (salivary testosterone and cortisol concentrations), and perceptual well-being (soreness, mood, stress, sleep quality and fatigue) markers were recorded. Although no single marker has established sensitivity to detect overall fatigue in sporting populations, these measures offer a useful method of monitoring the physical and emotional responses of athletes to a given workload.

The results demonstrated that fast bowlers consistently performed at greater intensities and performed more high-speed running than non-fast bowlers. Furthermore, fast bowlers exhibited greater physical-preparation and competition cortisol concentrations, lower competition testosterone concentrations, less perceptual fatigue during competition and similar CMJ performances to non-fast bowlers. Overall, these findings demonstrate differences in the physical demands of cricket fast bowlers and non-fast bowlers and that these external workloads differentially affect the neuromuscular, endocrine and perceptual fatigue responses of these players.

Fast bowlers completed greater external workloads (reflected by greater amounts of low-speed activity and high-speed running and higher player-load scores) during competition and physical preparation than non-fast bowlers.

These findings support previous studies identifying the physical demands of cricketers. They found higher cortisol concentrations across the physical-preparation and competition periods in fast bowlers than non-fast bowlers. The higher cortisol concentrations are possibly linked to the higher workloads and intensities of these players relative to non-fast bowlers. Alix-Sy *et al*. (2008) reported elevated cortisol concentrations during a pre-competition period in soccer players and showed that the endocrine responses coincided with increases in emotional stress. The poorer perceptions of well-being during competition coupled with the higher cortisol concentrations in the non-fast bowlers in the final 3 days of the competition period may reflect the greater psychological stress associated with batting in cricket. The results of the study also showed lower testosterone concentrations in fast bowlers during the competition period.

Previous studies of adolescent rugby players have identified testosterone concentrations as a better measure of tiredness (as estimated from a self-reported questionnaire) than cortisol concentrations. While their results are in general agreement with those of Maso *et al*. (2004) there may be differences in the training activities of rugby players and cricketers that require consideration when interpreting individual testosterone responses as a measure of tiredness.

A major new finding of the study was the uncoupling of neuromuscular, endocrine and perceptual fatigue markers in response to external load, particularly during the competition period. Although results from competition cortisol and testosterone concentrations suggested that fast bowlers were in a greater catabolic state than non-fast bowlers, neuromuscular function was maintained at levels comparable to that of the non-fast bowlers. Furthermore, fast bowlers reported less perceptual fatigue than non-fast bowlers. While the endocrine, neuromuscular, and perceptual measures used in this study have been routinely used as markers of fatigue, previous investigators have commonly reported that no single marker has adequate sensitivity to detect the fatigue associated with intense sporting activities. It is also possible that the sensitivity of some markers could be sport-specific. That is, the markers used to identify fatigue in some high-intensity (e.g., soccer) or collision (e.g., Australian football, rugby league) sports may differ from the markers used to identify fatigue in cricket.

While the physical demands of cricket match play have previously been described, no study had monitored markers of fatigue during preparation and competition periods in the same cricketers.

The above mentioned study by McNamara *et al*. (2013) monitored junior players and only over a physical preparation period of 7 weeks, with a 10 day competition period. The only ‘discipline’ categories were fast and non-fast bowlers. Batsmen and wicket keepers were not included. Knowing the workload of all ‘disciplines’ and individual players, during training and matches, is key to individualising training and recovery. 10Hz GPS units were used in this study. 15Hz GPS units are now available which provide more accurate results due to the increased sampling rate.

The following movement categories were used: low-speed activity (0 to 5 m/s), high-speed running (≥5.1 m/s) and sprinting (≥7.1 m/s). A higher number of categories will allow the data to be more specific and accurate when determining loads.

McNamara *et al*. (2013) conducted the study with u/19 cricket players and only compared fast bowlers to non-fast bowlers. Therefore, according to my knowledge, this may be the first study conducted at a semi-professional men’s level and the first to compare different bowling types as well as batsmen.

Furthermore, to the best of my knowledge, no study has compared internal and external training/match loads of cricket players.

Monitoring workloads in cricket players

Most of the research investigating workload in cricket, involved bowlers, and specifically fast bowlers with the focus on the relationship between workload and injury risk. Dennis *et al*. (2003) investigated 90 elite adult fast bowlers, and used balls bowled during a session, a week, and a month as load monitoring techniques. Results showed that bowlers who completed on average less than 123 or more than 188 deliveries during a week, had an increased risk of injury compared to those who bowled between 123 and 188 deliveries during a week. When looking at the relationship between bowling workload and injury in 12 elite adult fast bowlers, Dennis *et al*. (2004) showed that players who bowled more than five sessions in a week were 4.5 times more likely to get injured. Bowlers who bowled more than 522 balls in a 30-day period were at increased risk of injury. Load monitoring techniques included balls bowled during a session, a week, a month, as well as during the season. Bowling workloads in 44 elite junior cricket fast bowlers were also related to an increased risk of injury (Dennis *et al*., 2005). Methods to monitor load included a daily diary to report the balls bowled during match innings, training sessions a week, as well as balls bowled during a training session. Bowlers had a higher risk of injury if they bowled more than 2.5 days a week or more than 50 deliveries a day.

By using overs bowled during a match in 198 elite adult fast bowlers, Orchard *et al*. (2009) showed that players who bowled more than 50 overs in a 5-day match period, had an increased risk of injury in the next 21 days. The same results were found in a study analysing the overs bowled/match and injury risk in 235 elite adult fast bowlers (Orchard *et al*., 2015). Bowling workloads were monitored during time periods from five days to 26 days to show the increased injury rate during the month following the workload in players who bowled more than 50 match overs during a 5-day period.

Hulin *et al*. (2014) determined the external workload (balls bowled/week) and the internal workload (RPE x training duration) in 28 adults fast bowlers. A training stress balance was calculated by dividing the acute by the chronic workload, expressed as a percentage. A training stress balance more than 200% was associated with a higher risk of injury.

McNamara *et al*. (2013) used markers of neuromuscular, endocrine and perceptual fatigue to compare elite young fast bowlers (n=9) with non-fast bowlers (n=17). The load-monitoring methods used were GPS units, countermovement jump, and cortisol and testosterone concentration. Player responses to a seven-week preparation period and a 10-day competition period were compared. Fast bowlers covered greater total, low and high speed distances during competitions. Cortisol concentrations were higher for fast bowlers during the preparation and competition phases, and their testosterone concentrations were lower in the competition phase. The researchers also showed that there are differences between positional groups and individual responses to workloads.

SUMMARY

This overview was an investigation of the sport of cricket and its components. The review also covered literature pertaining to the use of GPS in athlete tracking and the particular use thereof in a cricket context. This chapter aimed to provide information on external- and internal training load, as well as the relationship between the two. Monitoring of fatigue and recovery was discussed. The major avenues of determining such loads and fatigue/recovery were mentioned. The increasing importance of sport science and the resulting player management was stated. Two major studies by McNamara *et al.* (2013) and Petersen *et al.* (2010) were analysed and the results were reported upon. Limitations in the current literature were brought forward and the plans to address these limitations were stated.

CHAPTER 3

METHODOLOGY

A. INTRODUCTION

The lack of literature involving cricket shows there is a need for studies that determine the training loads of all cricket disciplines and over an entire competitive season. Firstly, this chapter describes the design and outline of the current study. Mention is given to the ethical procedures and guidelines adhered to. The tests and measurements conducted during the study are described. Lastly, this chapter mentions the statistical methods which were used to analyse the data.

B. STUDY DESIGN

This descriptive study was carried out over a season in order to determine the loads placed on cricketers by the different formats, the resulting fatigue from these matches, and the game demands placed on different 'disciplines'. Participants were assigned to groups based on their role in the team. These roles/disciplines are ultimately based on the abilities of the player and what the coach requires from them. The disciplines for this study consist of fast bowlers, medium pace bowlers, batsmen, all-rounders whom are medium pace bowlers and all-rounders whom are spin bowlers. A fast bowler is a player whom specialises in delivering the ball at high speeds (130 km/h and above). A medium pace bowler is a player whom specialises in delivering the ball at a fairly quick speed (110-130 km/h). A batsmen is a player whom specialises in batting and only fields during the bowling innings. An all-rounder is a player whom is adept at both batting and bowling. A spin bowler is a player whom specialises in delivery the ball slowly, while imparting spin on the ball. The revolutions of the ball cause it to move left or right once it hits the pitch. Any player in the squad, who volunteered, was selected for this study if they met the inclusion criteria.

Data from the fielding and batting innings were combined in the comparison of the three different formats and of the five different player disciplines.

C. PARTICIPANTS

1. Recruitment

Participants were recruited by contacting the CEO of the relevant union and then the coach of the first class team. The participants were all members of the same team, from a union at which one of the former study leaders was affiliated, thus making it a sample of convenience.

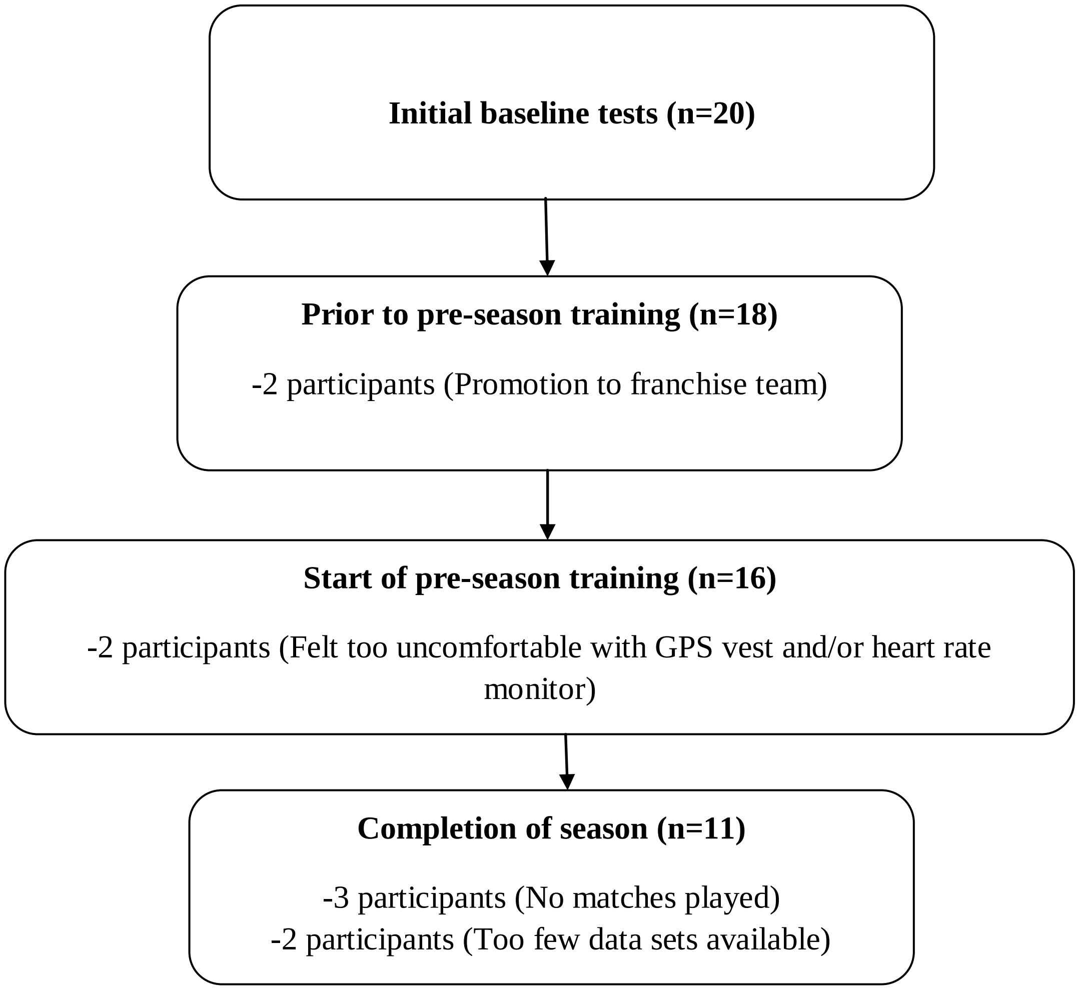

Figure 3.1 **Schematic representation of participant recruitment and study design**

The participants consisted of 2 fast bowlers, 1 medium-paced bowler, 3 batsmen, 2 all-rounders whom were medium-paced bowlers and 1 all-rounder whom was a spin bowler.

2. Inclusion and exclusion criteria

Participants were included in the study if they were a part of the first class team.

Participants were excluded from the study if a) they didn't take part in any matches over the season; b) they did not wear the data capturing devices during the season.

A participant's data for a particular session was excluded if they failed to wear both data capturing devices (GPS unit and heart rate monitor) during the session. The data from a batting innings was excluded if the innings duration was less than 30 minutes.

D. STUDY OUTLINE

The study was conducted over a period of one season, spanning six months. The study comprised two training sessions a week as well as one 'match weekend', unless a bye was assigned to the team. The season consisted of ten 'match weekends'. A 'match weekend' consisted of a 3-day match followed by a 50-over or T20 match on the fourth day. A mid-season break, consisting of two weeks, occurred over the Christmas and New Year period. Players were monitored during each day of a 'match weekend'. The saliva samples, which were collected to determine the concentration of biomarkers, were collected at three different time points during the season. The first was taken before any competitive phase training sessions or matches had occurred. The second was taken after two days of rest following the last game prior to the mid-season break. The third sample was taken after two days of rest following the last match of the season. The players also completed the

Training Distress Scale (TDS) at three different time points during the season. The first time point was after two days of rest, following the first two ‘match weekends’, played back-to-back. This served as the baseline score. The second and third occasions mimicked those of the biomarker testing schedule.

A total of 8 Three-day matches, 4 fifty-over matches and 3 T20 matches were analysed. The GPS data sets collected from these matches amounted to 53.

E. ETHICAL ASPECTS

The study protocol was approved by and carried out in a manner that conformed to the principles set out by the Ethics Committee of Research Subcommittee A at Stellenbosch University (Appendix B). Informed consent forms (Appendix A) were handed out to the participants at the first pre-season session. Informed consent and the study protocol was explained verbally to the participants at this session. The participants were allowed time to ask any questions regarding the informed consent, the testing protocols and the study in general. All participants were informed that participation in the study, and each test, was voluntary, and that they were allowed to withdraw from the study at any point without any justification. All participant information and questionnaire results were kept confidential. All participants signed the consent forms. There were no invasive aspects of the study and participants were not placed under any extra risk. All documentation and questionnaires were handled by the participants, researcher and study leaders. The documents were filed and stored in a locked room to which only the researcher and the study leader had access. Electronic copies were saved on a personal computer (password protected) and on external drives which could only be accessed by the researcher. All data used for analysis was safely and securely stored after completion of the study.

F. MEASUREMENTS AND TESTS

1. Anthropometric assessment

Stature

Stature was measured using a stadiometer. Participants were positioned with the heels together and the heels, buttocks and upper back touching the stadiometer. The participant's head was placed in the Frankfurt plane, the lower edge of the eye socket (Orbitale) in the same horizontal plane as the noth superior to the tragus of the ear (Tragion). Once in this position, the participants were instructed to inhale and the measurement was taken at the highest point of the skull, the Vertex. The reading was taken to the nearest 0.1 centimetre (cm).

Body weight

Body weight was measured using a calibrated electronic scale (Scalemaster, model JPS-1050) rounded off to the first decimal. Participants stood in the middle of the scale with weight evenly distributed, looking straight ahead.

2. GPS, Heart rate monitor, biomarker analysis, TDS

GPS Unit and Heart Rate Monitor (HRM)

Each player was assigned a GPS unit for the duration of the study. To ensure internal validity, the player used the same GPS unit for every session. The relevant GPS unit, a heart rate monitor and a vest were supplied to each player at the start of a match day. Each vest had a pocket situated at the back, positioned between the scapulae when worn. The GPS unit was switched on and placed inside the pocket. The heart rate monitor was placed around the chest, just below the sternum. The GPS unit was switched off after each playing session and switched back on just before the players took the field for the start of the next session.

Biomarker analysis

Biomarker concentration was measured from saliva samples. Each player was given a small plastic vial in which they had to deposit some saliva. The participants were given straws for the collection process if they wished to use them. The participants were allowed to drink water in order to induce salivation, but they were not allowed to deposit any water into the vial. The vials were sealed and placed on ice until being delivered to the testing laboratory. The saliva samples were taken at the same time of the day, 10:00, during each testing session, in order to negate the circadian rhythm of each biomaker.

Calibrators and Quality control samples

The stock solutions of Cortisol, DHEA and Testosterone were used to prepare a calibration range of seven calibrators between 30ng/ml as the upper limit of quantification (ULOQ) and 0.200ng/ml as the lower limit of quantification (LLOQ). Quality control (QC) samples were prepared from stock solutions at high (24.0), medium (12.0) and low (0.600) concentrations in duplicate. Blank samples (matrix with ISTD) and double blank (only matrix) samples were also included in each batch

Sample Preparation

Study samples were stored frozen, at the laboratory, before processing. On the day of processing, samples were defrosted at room temperature. Calibrators and QC samples were prepared fresh accordingly. Samples were centrifuged at 1200 rpm for 10 minutes before use to remove any debris. After centrifugation, 400 µl of each sample (including calibrators and QCs) was aliquoted to clean the glass tubes. Internal standard ISTD (100µl D4-solution) was added to represent 30.0 ng/ml in the final sample matrix. A liquid-liquid extraction was performed on the sample by adding 3.0 ml of tert-methyl-butyl ether (TMBE) to each tube. After addition of TBME, samples were vortexed for 2 minutes and then centrifuged for 5 minutes at 1200rpm. The aqueous layer was frozen in a -80°C freezer, for at least 30 minutes, where after the top layer of the unfrozen organic phase was decanted into clean glass tubes. The organic phase was then evaporated to dryness with Nitrogen gas in a nitrogen dryer (TurboVap) at 30°C for approximately 30 minutes. The residues were reconstituted with 200µl mobile phase (1:1 ratio of aqueous: organic) and vortexed for 15 seconds each before adding the samples to injector vials fitted with a 200ul insert. The vials were sealed and placed in the sample manager of the Waters Acquity™ UPLC, operated at 4°C, before injecting the samples into the UPLC system. Samples are quantified based on response area using MassLynx V4.1. A calibration curve was constructed for each batch and all unknowns and QCs were quantified based on the integrated area of its chromatogram, back calculated from this curve.

Training Distress Scale (TDS)

The TDS can be used to measure perceptual fatigue. The Training Distress Scale is a 19-item measure of training-related distress and performance readiness. These symptoms include a variety of complaints related to emotionality, general fatigue, concentration difficulties, physical discomfort, sleep disturbance and appetite changes (Grove *et al*., 2014). The severity of each symptom is rated from 0 – 4, which corresponds to 'not at all' and 'extreme amount'. A lower score is therefore favourable.

Three studies were conducted to validate the TDS. Study 1 was a randomized, controlled laboratory experiment in which a treatment group undertook daily interval training until a 25% decrement occurred in time-to-fatigue performance. Comparisons with a control group showed that TDS scores increased over time within the treatment group but not in the control group. Study 2 was a randomized, controlled field investigation in which performance capabilities and TDS responses were compared across a high-intensity interval training group and a control group that continued normal training. Running performance decreased significantly in the training group but not in the control group, and scores on the TDS mirrored those changes in performance capabilities. Study 3 examined the relationship between TDS scores obtained over a 2-week period before major swimming competitions and subsequent performance in those competitions. Significantly, better performance was observed for swimmers with low TDS scores compared with those with moderate or high TDS scores. These findings provide both laboratory and field evidence for the validity of the TDS as a measure of short-term training distress and performance readiness. Preliminary analyses on the TDS responses revealed very good internal consistency, with an average Cronbach's alpha of 0.88 over multiple administrations.

The training distress scale was given to each participant on the relevant testing day. The questionnaire had been explained previously to the participants and they were encouraged to ask questions if they were unsure about any aspect of the questionnaire. The players were required to rate certain physical or psychological symptoms felt over the course of the last 48 hours.

G. STATISTICAL ANALYSIS

Due to the normality of the data, parametric tests were conducted for statistical analysis. The level of significance was set at 95 % ($p \leq 0.05$). ANOVA's, followed by the Levene's test and Games-Howell post hoc test, were used to compare all the GPS variables between the different player disciplines. A mixed model repeated measures ANOVA was used to compare all the GPS variables between the different match formats. A mixed model repeated measures ANOVA was used to compare biomarker concentrations, and TDS scores, between the different testing sessions.

Effect sizes were calculated to determine if there were any practical significant differences between data sets. Relative effect size of Cohen's *d* was qualitatively assigned as follows: Small ($\geq 0.2\ d < 0.5$), Moderate ($\geq 0.5\ d < 0.8$), Large ($\geq 0.80\ d < 1.2$) and Very Large (≥ 1.2).

CHAPTER FOUR

RESULTS

A. INTRODUCTION

The results of the study will be presented in the following chapter. The data obtained from 11 participants was used for the final statistical analysis.

B. DESCRIPTIVE CHARACTERISTICS

Anthropometric characteristics

Table 4.1. Participant anthropometric measures. Values are means ± SD; N=11

Age	22.36 ± 2.80 years
Stature	179.36 ± 7.88 cm
Body weight	79.68 ± 7.51 kg

C. GPS VARIABLES

Formats

Statistically significant differences were found in the lower speed zones; namely standing, walking and jogging. 3-day matches resulted in a significantly higher percentage of standing than T20 matches. 3-day matches resulted in a higher percentage of distance covered by walking, compared to both 50-over and T20 matches. 3-day matches resulted in a higher percentage of distance covered by jogging, compared to both 50-over and T20 matches. No significant difference was found in the upper speed zones; namely striding, sprinting and maximal sprinting (Table 4.2.).

Table 4.2. **Movement category distances by match format (mean±SD)**

	Distance covered (% of total)					
Format	**Standing (0 - 1 km.h^{-1})**	**Walking (1 km.h-1 – 20 % Vmax)**	**Jogging (21 - 40 % Vmax)**	**Striding (41 - 70 % Vmax)**	**Sprinting (71 - 90 % Vmax)**	**Max sprinting (91 - 100 % Vmax)**
3-day	0.29 ± 0.17**^{BC}	70.01 ± 7.63*$^{+BC}$	13.76 ± 6.01$^{\#\wedge BC}$	12.65 ± 6.07^{AB}	3.03 ± 2.43	0.25 ± 0.29^{A}
50-over	0.21 ± 0.13^{AB}	63.54 ± 9.61*^{B}	17.18 ± 5.48$^{\#AB}$	15.41 ± 6.07^{A}	3.31 ± 3.74	0.36 ± 0.69^{A}
T20	0.17 ± 0.12**^{AC}	60.41 ± 10.10^{+C}	19.85 ± 6.15^^{AC}	15.98 ± 6.07^{B}	3.26 ± 3.10	0.14 ± 0.22^{A}

*P<0.05 Statistically significant difference for walking between 3-day and 50-over matches

+P<0.05 Statistically significant difference for walking between 3-day and T20 matches

**P<0.05 Statistically significant difference for standing between 3-day and T20 matches

#P<0.05 Statistically significant difference jogging between 3-day and 50-over matches

^P<0.05 Statistically significant difference for jogging between 3-day and T20 matches

A Effect size = Small

B Effect size = Moderate

C Effect size = Large

No significant differences were found between the formats for any of the heart rate zones ($P > 0.05$) (Table 4.3).

Table 4.3. Percentage of match time spent in heart rate zones by match format (mean±SD)

	Time in HR zones (% of total)					
Format	**0 - 50%**	**51 - 60 %**	**61 - 70%**	**71 - 80%**	**81 - 90%**	**91 - 100%**
3-day	20.66 ± 25.92^{AA}	20.82 ± 17.14	24.10 ± 14.38	22.60 ± 17.37^{A}	10.07 ± 8.16^{A}	1.61 ± 1.99^{A}
50-over	13.00 ± 22.02^{A}	19.82 ± 17.88	25.07 ± 15.78	20.11 ± 13.71	12.55 ± 13.47	3.66 ± 5.66^{A}
T20	12.92 ± 17.18^{A}	22.50 ± 20.91	24.72 ± 14.32	19.21 ± 13.75^{A}	15.10 ± 14.73^{A}	5.68 ± 12.97^{A}

A and A Effect size = Small

A statistically significant difference was found between the total distance covered during a 3-day innings and that during a T20 innings. Players covered more distance during a 3-day match innings than a T20 innings.

No significant differences were found between the match formats for 'New Total Body Load' , 'Maximum speed reached' and 'Maximum heart rate obtained' (Table 4.4.).

Table 4.4. Load variables by match format (mean±SD)

Format	**New Total Body Load**	**Distance (m)**	**Max Speed (km/h)**	**Max HR (beats/min)**
3-day	155.57 ± 143.98^{B}	6112.98 ± 5152.83*^{AC}	27.64 ± 3.14^{A}	181.89 ± 13.81^{A}
50 over	160.79 ± 121.29^{B}	5004.08 ± 3045.51^{AC}	27.67 ± 2.28^{B}	187.32 ± 11.72^{AA}
T20	95.65 ± 61.27^{BB}	2895.97 ± 1605.00*^{CC}	26.50 ± 2.28^{AB}	183.68 ± 15.73^{A}

*$P<0.05$ Statistically significant difference for distance between 3-day and T20 matches

A and A Effect size = Small

B and B Effect size = Moderate

C and C Effect size = Large

Player disciplines

Statistically significant differences were found in the sprinting speed zone. No significant differences were found in the rest of the speed zones (Table 4.5.). Fast bowlers covered a greater percentage in this zone compared to medium-paced bowlers, batsmen and all-rounders whom are spin bowlers. All-rounder medium-paced bowlers covered a greater percentage compared to batsmen.

Table 4.5. Movement category distances by player discipline (mean±SD)

	Distance covered (% of total)					
Discipline	**Standing (0 - 1 km.h^{-1})**	**Walking (1 km.h^{-1} - 20% Vmax)**	**Jogging (21 - 40% Vmax)**	**Striding (41 - 70% Vmax)**	**Sprinting (71 - 90% Vmax)**	**Max sprinting (91 - 100% Vmax)**
Fast bowler (n=2)	0.20 ± 0.13[ABC]	67.63 ± 7.90[B]	11.53 ± 2.82[BCCC]	13.57 ± 3.56[BBB]	6.59 ± 4.34*[+^BBCD]	0.46 ± 0.97[AB]
Medium pace bowler (n=1)	0.13 ± 0.14[BBB]	69.04 ± 4.39[AC]	15.30 ± 7.19[AB]	11.67 ± 2.46[ABB]	3.50 ± 3.09*[BBB]	0.35 ± 0.44[D]
Batsman (n=3)	0.25 ± 0.16A[AAB]	66.55 ± 12.06[AA]	16.42 ± 4.93[AC]	14.64 ± 10.49[A]	2.04 ± 2.07[+#BDD]	0.10 ± 0.09[BDD]
All-rounder (Medium pace bowler)	0.22 ± 0.12[ABC]	61.89 ± 8.21[ABBC]	16.82 ± 6.17[AAC]	16.18 ± 6.03[BB]	4.45 ± 1.84[#BBDD]	0.34 ± 0.28[CD]

(n=2)						
All-rounder (Spin bowler) (n=1)	0.32 ± 0.17^{ACC}	67.75 ± 7.37^{B}	14.11 ± 4.05^{AAC}	16.10 ± 10.12^{B}	$1.68 \pm 0.60^{\wedge CD}$	0.05 ± 0.10^{AC}

*P<0.05 Statistically significant difference for sprinting between Fast bowler and Medium pace bowler

+P<0.05 Statistically significant difference for sprinting between Fast bowler and Batsman

^P<0.05 Statistically significant difference for sprinting between Fast bowler and All-rounder (spin bowler)

#P<0.05 Statistically significant difference for sprinting between Batsman and All-rounder (medium pace bowler)

A, A, A Effect size = Small

B, B, B, B Effect size = Moderate

C, C, C Effect size = Large

D, D, D Effect size = Very Large

No significant differences were found between the disciplines for any of the heart rate zones

($P > 0.05$) (Table 4.6.).

Table 4.6.Percentage of match time spent in heart rate zones by player discipline (mean±SD)

	Time in HR zones (% of total)					
Discipline	**0 - 50%**	**51 - 60 %**	**61 - 70%**	**71 - 80%**	**81 - 90%**	**91 - 100%**
Fast bowler (n=2)	15.30 ± 18.86^{AA}	25.74 ± 17.42^{A}	25.83 ± 13.96^{A}	21.11 ± 13.28^{A}	11.13 ± 6.63^{AAA}	0.80 ± 1.40^{ACCD}
Medium pace bowler (n=1)	23.00 ± 22.97^{AAC}	27.55 ± 14.70^{AA}	20.24 ± 10.03^{AAA}	17.13 ± 12.80^{AA}	8.38 ± 6.78^{AAB}	3.62 ± 5.19^{D}
Batsman (n=3)	16.46 ± 28.33^{AA}	18.65 ± 21.25^{AAAA}	24.69 ± 16.16^{A}	22.61 ± 18.38^{A}	13.28 ± 14.72^{A}	4.16 ± 11.54^{A}
All-rounder (Medium pace bowler) (n=2)	9.69 ± 13.91^{AAAC}	23.15 ± 17.65^{AA}	27.43 ± 16.18^{A}	19.38 ± 12.43^{A}	15.80 ± 14.65^{AAB}	4.51 ± 6.35^{AC}
All-rounder (Spin bowler) (n=1)	13.90 ± 18.77^{A}	23.53 ± 18.44^{A}	25.87 ± 10.08	22.16 ± 15.14 ^{A}	12.46 ± 11.41^{AA}	2.04 ± 2.08^{AC}

A, A, A, A, A Effect size = Small

B Effect size = Moderate

C, C Effect size = Large

D Effect size = Very Large

Statistically significant differences were found between disciplines for 'New Total Body Load' and 'Maximum heart rate obtained'.

Fast bowlers recorded a higher 'New Total Body Load' score than the Batsmen and All-rounders who were spin bowlers.

Medium-paced bowlers recorded a higher maximum heart rate than the Fast bowlers, Batsmen and all-rounders whom are medium-paced bowlers (Table 4.7.).

Table 4.7. Load variables by player discipline (mean±SD)

Discipline	New Total Body Load	Distance (m)	Max Speed (km/h)	Max HR (beats/min)
Fast bowler (n=2)	219.89 ± 186.55$^{\text{**+ABD}}$	6949.77 ± 6046.21$^{\text{AAC}}$	28.37 ± 4.23$^{\text{AB}}$	180.13 ± 14.22*$^{\text{BBD}}$
Medium pace bowler (n=1)	187.18 ± 116.60$^{\text{D}}$	6162.36 ± 3958.68$^{\text{AD}}$	28.45 ± 1.05$^{\text{AC}}$	204.10 ± 9.48$^{\text{*\#\^{}DDD}}$
Batsman (n=3)	72.95 ± 34.07**$^{\text{ADDD}}$	3624.50 ± 1916.96$^{\text{ABCD}}$	26.42 ± 2.46$^{\text{BBBC}}$	179.37 ± 13.92$^{\text{\#BBD}}$
All-rounder (Medium pace bowler) (n=2)	185.22 ± 113.96$^{\text{ACD}}$	5125.43 ± 2859.22$^{\text{AAAB}}$	27.70 ± 2.20$^{\text{AAB}}$	188.75 ± 6.55$^{\text{\^{}ABBD}}$
All-rounder (Spin bowler) (n=1)	89.50 ± 59.23$^{\text{+ABC}}$	4054.28 ± 3047.29$^{\text{AAA}}$	27.66 ± 1.58$^{\text{B}}$	190.40 ± 4.83$^{\text{ABB}}$

**P<0.05 Statistically significant difference for New Total Body Load between Fast bowler and Batsman

+P<0.05 Statistically significant difference for New Total Body Load between Fast bowler and All-rounder (Spin bowler)

*P<0.05 Statistically significant difference for Max HR between Fast bowler and Medium pace bowler

#P<0.05 Statistically significant difference for Max HR between Medium pace bowler and Batsman

^P<0.05 Statistically significant difference for Max HR between Medium pace bowler and All-rounder (Medium pace bowler)

A, A, A, A Effect size = Small

B, B, B, B Effect size = Moderate

C Effect size = Large

D, D, D Effect size = Very Large

D. BIOMARKERS

No significant differences were found between testing sessions for Testosterone and DHEA. (P > 0.05) There was a significant difference between the Baseline and Mid-season testing sessions for Cortisol. (P < 0.05) (Figure 4.1.).

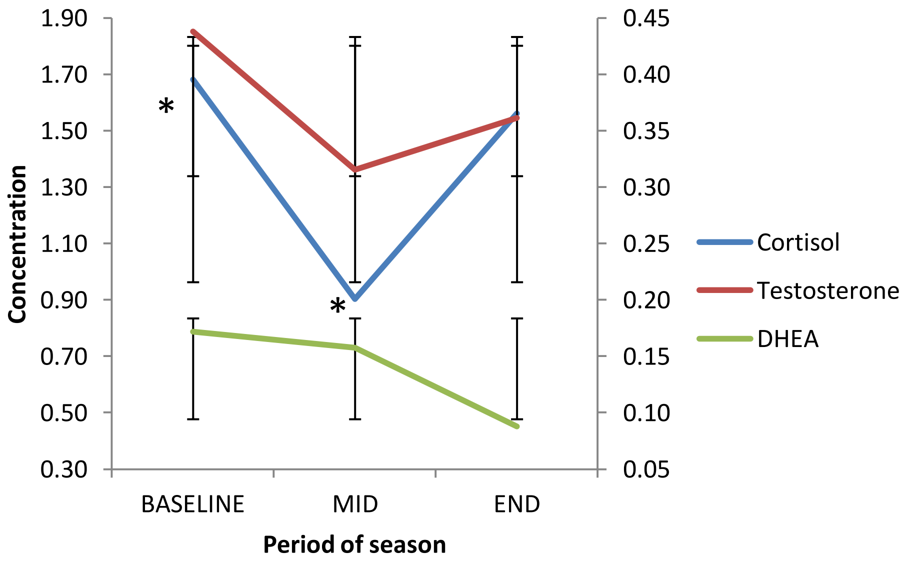

Figure 4.1. Comparison of biomarker concentrations during the competitive season.

**P<0.05 Statistically significant difference for Cortisol concentration between baseline and mid-season testing sessions

Table 4.8. Effect sizes of the comparison of biomarker concentrations.

Biomarker	Comparison	Effect size
Cortisol	Baseline – Mid-season	Large
Cortisol	Mid – End of season	Very Large
Testosterone	Baseline – Mid-season	Large
Testosterone	Baseline – End of season	Moderate
Testosterone	Mid – End of season	Small
DHEA	Baseline – End of season	Large
DHEA	Mid – End of season	Very Large

No significant differences were found between testing sessions for the Testosterone-to-Cortisol ratio .

(P > 0.05) (Figure 4.2.).

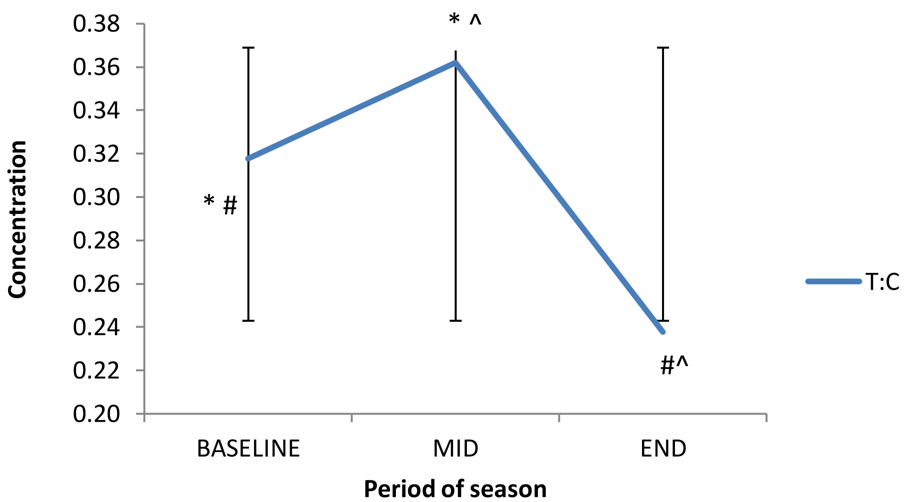

Figure 4.2. Testosterone-to-Cortisol ratio across the competitive season.

* Effect size = Small (*d* = 0.26)

Effect size = Moderate (*d* = 0.61)

^ Effect size = Large (*d* = 1.02)

E. TRAINING DISTRESS SCALE

No significant differences were found between the testing sessions for the TDS scores ($P > 0.05$) (Figure 4.3.).

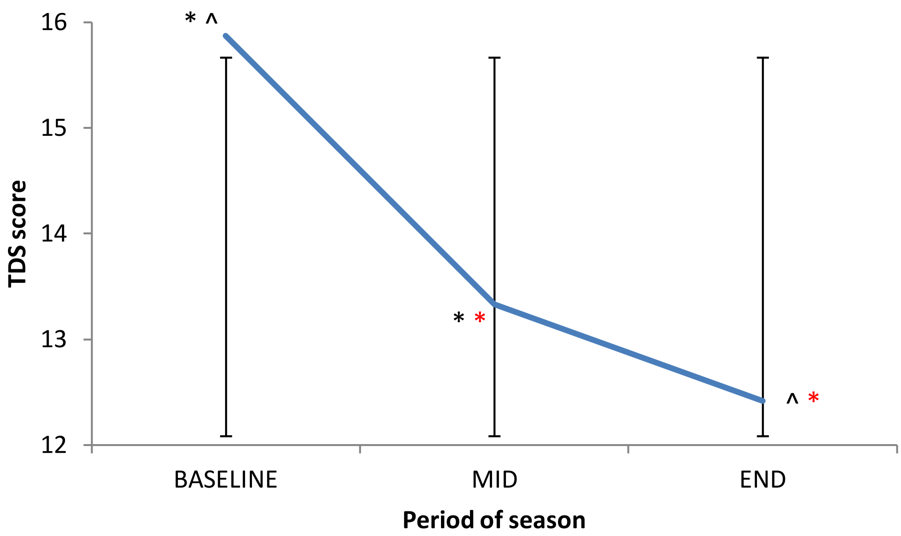

Figure 4.3. TDS scores across the competitive season.

* Effect size = Small (*d = 0.48)*

* Effect size = Small (*d* = 0.49)

^ Effect size = Large (*d* = 0.94)

CHAPTER FIVE

DISCUSSION

A. INTRODUCTION

The aim of the current study was to monitor match loads, as well as recovery and fatigue, of players (N=11) from a semi-professional cricket team over a competitive season. The specific objectives of the study were to:

1. Determine loads in high-level cricket players over a competitive cricket season.
2. Determine differences in match format loads over a competitive cricket season.
3. Determine position-specific loads of batsmen, bowlers, and all-rounders over a competitive cricket season.
4. Determine match format specific loads of batsmen, bowlers, and all-rounders over a competitive cricket season.
5. Determine the cortisol responses in high-level cricket players over a competitive season.
6. Determine the testosterone responses in high-level cricket players over a competitive season.
7. Determine the dehydroepiandrosterone (DHEA) responses in high-level cricket players over a competitive season.
8. Determine the differences in cortisol responses between batsmen, bowlers, and all-rounders over a competitive season.
9. Determine the differences in testosterone responses between batsmen, bowlers, and all-rounders over a competitive season.
10. Determine the differences in dehydroepiandrosterone (DHEA) responses between batsmen, bowlers, and all-rounders over a competitive season.

To the researchers knowledge, Petersen and colleagues (2010) are the only researchers to have reported on the match loads of the different formats and player disciplines. This results in difficulties when comparing this study to others. The researcher will therefore mostly refer to the work done by Petersen and colleagues (2010).

The main findings of the study will be discussed according to the objectives mentioned above. Thereafter, final conclusions will be made. Limitations of the current study will be identified and recommendations for future studies discussed.

B. GPS VARIABLES

Three match formats

Statistically significant differences were found between the different formats in the lower speed zones; namely standing, walking and jogging. A significantly higher percentage of standing occurred in 3-day matches than T20 matches. A higher percentage of distance covered by walking was also found in the 3-day matches compared to both 50-over and T20 matches. Three-day matches resulted in a higher percentage of distance covered by jogging, compared to both 50-over and T20 matches. These results are similar, to a certain extent, to those found by Petersen *et al.* (2010). Petersen *et al.* (2010) found that 20-over matches resulted in higher average intensities than 50-over and multiday cricket. The results of the current study are similar in that players covered a greater percentage of distance by jogging in 3-day matches, but there were no statistically significant differences between the two shorter formats of the game. The results of the current study differ to those found by Petersen *et al.* (2010) in that there were no statistically significant differences found between formats in the upper speed zones (41 – 100% Vmax).

There was a lack of data for some disciplines (e.g. wicket-keeper and spin bowler). Therefore, all the players were grouped for each format. Data was used from the entire match for the T20 and 50-

over matches. For 3-day matches, the entire first innings data was used. This means that the batting and bowling innings were combined for each player, and therefore each discipline as a whole. Differences between disciplines may exist across formats. However these differences may be nullified by differences in other disciplines. For example, if fast bowlers covered 10% of their total distance by sprinting (71 – 90% Vmax) during 3-day matches and 50% of their total distance by sprinting in T20 matches, T20 matches resulted in five times more distanced covered by sprinting. If medium pace bowlers covered 50 % of their total distance by sprinting (71 – 90% Vmax) during 3-day matches and 10% of their total distance by sprinting in T20 matches, 3-day matches resulted in five times more distanced covered by sprinting. This could result in no statistically significance differences overall, between the formats.

The fact that there were no differences between the formats in terms of the upper speed zones, in the current study, could be due to the fact that situations in a match depict the amount of effort required and therefore the load on players. If the batting team is not required to score runs quickly, the batsmen may not have to sprint between the wickets as easy singles may be taken. This low load would be contradictory to popular belief, as you would expect batsmen to have a fair amount of sprints in a T20 match as they look to score quickly and rotate the strike. For bowlers, the intensity at which the run-up is performed should be fairly constant between multi-day matches and the two shorter formats. The speed at which the bowler approaches the crease plays a big role in the rhythm of the run-up. Therefore, it would make sense that the run-up speeds remain fairly constant, regardless of the match format. For T20 matches, each fast bowler has a maximum of four overs. Naturally, the bowler can exert more effort over these four overs than they would be able to in a multi-day match, where there are no limits as to how many overs a single bowler may bowl. Regardless of the format, the movement patterns of the bowlers, while not bowling, remain fairly similar. The multi-day matches would result in a higher load, but the percentage of time spent in the different speed zones should be constant across the match formats. Once again the match situation plays a role. During multi-day matches, if the fielding team need to restrict the runs due to the situation of the game, the fast bowlers, while fielding, might be sprinting to the ball as they would in the shorter formats.

No significant differences were found between the formats for any of the heart rate zones. Heart rate is directly proportional to the intensity of exercise, so this variable showed that there was no difference in intensity between the disciplines. However, heart rate is only one indication of intensity.

A statistically significant difference was found between the total distance covered during a 3-day innings and that during a T20 innings. Players covered more distance during a 3-day match inning's than a T20 innings.

No statistically significant differences were found between the formats for 'New Total Body Load'. Body load (measured as G-force) is the collation of all forces imposed on an athlete, including acceleration/deceleration, related changes of direction and impacts from both the player-to-player collision and contact with the ground (foot strikes and falls). This may be due to the fact that no differences were found between the intensities at which the players worked, judging from the other intensity variables (distance covered in speed zones and time spent in heart rate zones). If there were differences present between the intensity variables, a difference in 'New Total Body Load' would be expected.

Player disciplines

Statistically significant differences were found in the sprinting speed zone between bowlers (fast and medium pace), batsmen and all-rounders (medium pace and spin bowlers). Fast bowlers covered a higher percentage in the sprinting speed zone compared to medium bowlers, batsmen and all-rounder spin bowlers. All-rounder medium pace bowlers covered a greater percentage of distance in the sprinting speed zone, compared to batsmen. Petersen *et al*. (2010) stated that marked differences in movement patterns were evident between disciplines and game formats, with fast bowlers undertaking the greatest workload. Fast bowlers sprinted twice as often, covered over three times the distance sprinting, with much smaller work-to-recovery ratios. In the current study, the percentage of distance that fast bowlers covered by sprinting was 1.9 times greater than the percentage of distance covered by Medium pace bowlers, 3.2 times greater than that covered by batsmen, and 3.9 times greater than that covered by all-rounders who bowl spin. Petersen and colleagues (2010) also stated that fast bowlers covered a greater total distance than non-fast bowlers. In the current study, the total distance covered by fast bowlers was 1.1 times greater than the total distance covered by medium pace bowlers, 1.4 times greater than that covered by all-rounders who bowl medium pace, 1.7 times greater than that covered by all-rounders who bowl spin, and 1,9 times greater than that covered by batsmen. The results of the current study are therefore in agreement with the work done by Petersen and his colleagues (2010). No significant differences were found in the rest of the speed zones, as well as for the maximum speed reached between players from the various disciplines.

No significant differences were found between the disciplines for any of the heart rate zones. Heart rate is directly proportional to the intensity of exercise, so this variable showed that there was no difference in intensity between the disciplines. However, heart rate is only one indication of intensity.

Statistically significant differences were found between disciplines for ‘New Total Body Load’. Fast bowlers recorded a higher ‘New Total Body Load’ score than the Batsmen and All-rounders who were spin bowlers. Due to the effort that fast bowlers exert and the resulting force during the delivery stride, it makes sense that fast-bowlers would register the highest scores for ‘New Total Body Load’. This also supports the statement from Petersen *et al*. (2010) that fast bowlers undertake the greatest workload.

No statistically significant difference was found in distance covered, between the disciplines. However, fast bowlers did cover 1.9 times the distance covered by batsmen and 1.7 times the distance covered by all-rounders that bowl spin. This shows that fast bowlers do cover greater distances than most of the other disciplines. The small sample size of the current study may be a contributing factor to the lack of statistical significance. The sample size of 11 is small in comparison to that of 42 in the study conducted by Petersen *et al*. (2010).

C. BIOMARKERS

Testosterone is one of the major anabolic hormones in males. Physical exercise is known to affect many hormones in the endocrine system and testosterone is no exception. Reductions in testosterone, if extensive and prolonged, can compromise a persons' health status. Relative to athletes, these reductions can negatively impact on the adaptation process associated with skeletal muscle, (i.e., myoplasticity) which is fundamental and necessary to the exercise training progression and improvement in performance.

Cortisol and dehydroepiandrosterone (DHEA) are stress hormones of the hypothalamic-pituitary-adrenal (HPA) axis. Cortisol is involved in a number of important functions, including responses to stress, energy metabolism, vascular activity and inflammatory and immune responses. DHEA is a precursor to sex hormones; it has been proposed to affect various systems of the body and be anti-ageing and immune enhancing

The effects of physical exercise on [cortisol] and [testosterone] levels have been widely documented, with particular reference to the fact that [cortisol] varies in the opposite direction to [testosterone], thus, showing that physical exercise produces an imbalance between the anabolic hormone of testicular origin and the catabolic hormone of adrenal origin.

There was a significant difference between the Baseline and Mid-season testing sessions for Cortisol, with the concentration decreasing from 1.7 to 0.9 mmol/l. No significant differences were found between testing sessions for Testosterone and DHEA. No significant differences were found between testing sessions for the Testosterone-to-Cortisol ratio.

Izawa *et al.*, (2008) investigated dehydroepiandrosterone (DHEA) secretion in response to acute psychosocial stress and the relations of DHEA secretion to cortisol secretion, cardiovascular activity, and negative mood changes. Thirty-three male students (mean age 22.6 years) were subjected to the psychosocial stress test ‘‘Trier Social Stress Test’’ (TSST), in which the participants were asked to deliver a speech and perform a mental arithmetic task in front of two audiences. On arrival, subjects initially rested for 10 min before they were introduced to the tasks (baseline: BL). Following the introduction, subjects were asked to prepare the public speech for 10 min (preparation period: PR), delivered a speech for 5 min (speech period: SP), and performed a mental arithmetic task for 5 min (mental arithmetic task period: MA). Thereafter, subjects rested for 30 min (recovery period: RE).

The main secretagogue for DHEA is adrenocorticotrophic hormone (ACTH). This hormone is supposed to affect several metabolic and immunological functions and be associated with lower incidence of ischemic heart disease and mortality from cardiovascular disease. Furthermore, DHEA is supposed to affect some brain functions through modulating neurotransmitter receptors, such as GABA-A receptor or NMDA receptor, and to be involved in the pathophysiology of cognitive decline and mood disorders. It is thought that the psychosocial stressor is one of the factors that alter the secretion of DHEA. However, few studies have investigated the relationship between secretion of DHEA and psychosocial stressors. Past studies have reported that lower DHEA levels were associated with poorer psychological well being in healthy elderly people. Some pharmacological studies have found that DHEA administration improved moods in healthy young men and decreased depressive symptoms in patients with major depression and HIV/AIDS. Other studies have not found the effect of DHEA administration on moods in healthy elderly people. Moreover, the endocrine balance between DHEA and cortisol has received attention. It was reported that the cortisol/DHEA ratio was elevated in depressive patients and that in adolescents high cortisol/DHEA ratio was predictive of persistent major depression. These results indicated that the effects of DHEA on moods were dependent on the contexts such as characteristics of participants (healthy people or patients, older or younger people), situations (stressful or non-stressful), and variations of other hormones such as cortisol. Most studies investigated the effects of DHEA administration on moods, but not the role of DHEA secretion in response to psychosocial stressors in the improvement of moods. The principal finding of the study by Izawa and colleagues. (2008) was that acute psychosocial stress increased DHEA concentrations. The relationship between DHEA and cortisol secretion was investigated. DHEA secretion was moderately correlated to cortisol secretion. Considering that cortisol secretion under the stressful situations is induced by increased ACTH secretion and that ACTH infusions increased DHEA, acute psychosocial stress increased DHEA concentration through increased ACTH secretion. However, a peak of DHEA concentration preceded that of cortisol concentration by about 10 min. This delay was unexpected ,because it has been thought that DHEA was secreted synchronously with cortisol during the night as well as during the day. To the knowledge of Izawa and colleagues. (2008) , their study was the first study that demonstrated the difference in time-course variation of DHEA and cortisol secretion in response to acute psychosocial stress. A recent study demonstrated that although cortisol exhibited a clear increase after awakening, DHEA did not exhibit such a clear increase after awakening. Interestingly, this study showed that negative mood was associated with DHEA or cortisol/DHEA ratio during early phase of TSST (PR and MA), in which DHEA concentration started to increase, but cortisol concentration did not. There is a possibility that an earlier increase in DHEA concentration contributed for reducing negative mood during stressful situation. There may be physiological mechanisms that differentiate DHEA response from cortisol response to acute psychosocial stress. The increase in DHEA concentration and its ratio to cortisol concentration may be important in reducing negative mood under the stressful situation. In conclusion, the study by Izawa *et al.*, (2008) demonstrated that the acute psychosocial increased secretion of DHEA in saliva, and presented the relation of the DHEA secretion to cortisol secretion and negative mood during and after TSST. An acute increase in DHEA concentration under stressful situations might have some significance in the improvement of negative mood.

In the current study, Cortisol and DHEA concentration decreased from the baseline to the mid-season testing session. In this case the decrease in Cortisol concentration is not accompanied by an increase in the concentration of DHEA. From the mid-season testing session to the end of season testing session, the Cortisol concentration increases whereas the DHEA concentration decreases. This is contrary to what one expects, but at present we have no scientific reasoning to offer in order to explain this phenomenon in our study.

In a study on eight professional male basketball players, conducted by Schelling *et al*. (2014), Total Testosterone (TT) concentration showed significant variations between blood samples: Second last month of season *vs.* Last month of pre-season (-4.4 nMol/l), Second last month of season *vs.* First month of season (-4.9 nMol/l) and Second last month of season *vs.* Middle of season (-6.8 nMol/l). TT did not correlate with playing time nor with Cortisol. Cortisol concentration did not show significant variations throughout the season and did not correlate with playing time. Finally, TT/C ratio did not show significant variations throughout the season.

Chronobiology indicates that Cortisol should display its highest values in autumn and winter and its lowest values in spring and summer. In Schelling’s study (2014), Cortisol shows its lowest values in November (autumn) and its highest values in April (spring), increasing progressively throughout the season, even if not significantly. These results would coincide with the hypothesis that Cortisol increases in relation to workload volume and stress. This is in accordance with the investigation of González-Bono *et al*. (2002) where an increase in Cortisol related to increases in workload volume was found in professional basketball players and with the results of Argus *et al*. (2009) where an increase was observed during a 13-week rugby competition.

The effects of physical exercise on cortisol [C] and testosterone [T] levels have been widely documented, with particular reference to the fact that [C] varies in the opposite direction to [T], thus, showing that physical exercise produces an imbalance between the anabolic hormone of testicular origin and the catabolic hormone of adrenal origin. Many studies have used the T/C ratio to emphasize the variations in these two hormones during the training season. This ratio diminishes when the training load increases, conversely below a certain threshold, it may indicate a state of overtraining. This imbalance may also be caused by a situation of stress resulting from the mental strain or the coupling of mental and physical strain (Elloumi *et al.*, 2003)

As mentioned above, Cortisol can increase due to stress. In the current study, the Baseline testing session was conducted following the pre-season and the first two 'match weekends' of the season. Four matches were played over this period, with the team drawing two and losing two. The team underwent a tough travel schedule during these two weeks and spent a lot of time fielding during the second 'match weekend'. The state of well-being of the players, coupled with the travel schedule and high training load may be the cause of the high cortisol concentration for the baseline reading.

Between the baseline and mid-season testing sessions, the team took part in four 'match weekends', two of which were played at home. Out of the seven matches played during this period, the team won four, drew one and lost two. This period was a more successful one for the team and could have led to a strong sense of well-being amongst the players. This sense of well-being coupled with the less gruelling travel schedule may have been the cause of the drop in cortisol concentration from baseline to the mid-season testing session.

To the researchers knowledge, this may be the first study on cricket players over a season. In that regard, there is no other research to use as a comparison.

D. TRAINING DISTRESS SCALE

No significant differences were found between the testing sessions for the TDS scores.

However, the questionnaire score dropped by 16% from baseline to mid-season (Small effect, *d* = 0.48), by 6.8% from mid-season to end of season (Small effect, *d* = 0.49) and by 21.7% from baseline to end of season (Large effect, *d* = 0.94) Even though there was no statistically significant difference, 16 and 21.7% are quite noticeable differences and effect sizes showed these differences. Once again, the small sample size of the current study may be a contributing factor to the lack of statistical significance.

The baseline score was obtained after two days of rest, following the first two 'match weekends', played back-to-back. The second was obtained after two days of rest following the last game prior to the mid-season break. The third sample was taken after two days of rest following the last match of the season.

It would be expected that the scores increase throughout the season. A possible reason for the higher baseline score could be the fact the score was obtained following back-to-back matches, played at two different venues. The players had played four days of cricket, rested for one day, travelled to the next venue (four and a half hour flight), practiced the next day, played four days of cricket and then travelled back home (two hour flight). Between the baseline and mid-season score, two out of the four 'match weekends' were played at home and there were three bye weekends, during which there were no matches played. This less vigorous travelling and match schedule may have contributed to a better well-being of the participants and therefore lower scores for the questionnaire. Between the mid-season and end of season scores, there was a mid-season break of five weeks, two 'match weekends' back-to-back followed by two bye weekends and then the final two 'match weekends' of the season, played back-to-back. All of these four 'match weekends' were played at home. During the second half of the season, no travelling was done and there was an absence of matches for two weeks out of the six weeks of competition. These factors may have played a big role in the further decrease in the questionnaire scores.

A study by Grove *et al*. (2014) supports the link between performance and TDS scores. The sample consisted of high-level age-group swimmers (*N* = 63) from three swimming squads at two local clubs. Participants were training to compete in either the Australian National Open Age Swimming Trials or the Western Australia State Championships. Both males (*n* = 25) and females (*n* = 38) participated in the study, ranging in age from 11 to 17 years (*M*age = 14.43 years). The TDS was used to assess training state and the severity of training distress symptoms. Because most participants competed in more than one event, the data set consisted of 130 pairs of TDS scores and performance scores. These paired observations were divided into three groups on the basis of whether the percentile rank of the total TDS score for the 2-week pre-competition period was low (i.e., 30th percentile or below; *n* = 50), moderate (i.e., 35th–65th percentiles; *n* = 39), or high (i.e., 70th percentile and above; *n* = 41). Groups were then compared on average times swum during competition using a difference score, which was created by subtracting the time swum in a particular event during the competition from the participant's previous personal best time in that event. Results of a one-way ANOVA, which assessed the relationship between training state and performance over the 2-week period prior to competition showed a significant difference in performance between the TDS groups. Follow-up comparisons using Tukey's honestly significant difference procedure indicated that participants scoring low on the TDS during the 2 weeks prior to competition swam significantly better than those scoring moderate or high on the TDS. The findings therefore demonstrate a link between TDS scores and performance in competition, providing key validity evidence for the TDS as a measure of training state and readiness to perform.

E. CONCLUSION

This study found that there were no overall differences between the match formats in terms of intensity. Three-day matches did, however, result in a greater volume in terms of distance covered during an innings.

Fast bowlers were the discipline that underwent the most load across the three match formats. They covered greater distances by sprinting and recorded higher total body load scores.

It was found that cortisol concentration decreased significantly from baseline to the middle of the season testing session. The concentration then increased from the middle point to the end of the season. The increased cortisol concentration during the second half of the season could demonstrate the accumulated fatigue resulting from the loads over the season. This is worth noting for the coaching staff and the strength and conditioning coach. They can plan the periodization of training to combat this part of the season, where the fatigue seems to show. Training loads can be planned accordingly to manage the players during this period and bring them through it injury free, while still maintaining performance.

The TDS scores decreased steadily throughout the season. Load that players experience can be physical as well as emotional/psychological. The TDS scores in this study mirrored the results of the matches. It is difficult to pinpoint the contributions of physical load and emotional/psychological load towards the overall load. The best a trainer can do is analyse the individual performance of players, together with the team performance, and link this with the physical load on the player. Both loads are important to manage to ensure the player's well-being.

With the results of the current study in mind, the following aspects could be important to coaches and the strength and conditioning staff:

- General conditioning: The lack of difference in intensities between the match formats shows that training sessions do not have to be tailored in accordance with the upcoming competitions, in situations where the different match formats are played at different times of the season.

- Higher physical demand on fast bowlers: The higher load, compared to other player disciplines, requires the fast bowlers to be better trained in order to cope with the greater load placed on them. The higher load also suggests that fast bowlers need to be managed extremely carefully to prevent burn-out. Training load should be managed because continuous, excessive loads are detrimental to players and fast bowlers are important players for their teams.

- Stress of travel and competition: The analysis of the cortisol concentration, together with the travel and match schedule, and the results of the games, suggest that these factors are important to take note of. An effort should be made to monitor these aspects and combat the possible detrimental effects. If fatigue is managed and dispersed effectively, the load the players undertake towards the end of the season should be manageable.

- Recovery management of players: Fast bowlers, due to their higher workload, will need more recovery time between sessions, or their workload needs to be managed carefully in accordance with the workload of previous sessions, if they are expected to perform optimally. Recovery strategies should be tailored to suit the individual needs of players.

F. LIMITATIONS AND FUTURE RECOMMENDATIONS

For the current study, only one innings of each of the 3-day matches was incorporated into the statistical analysis. Initially it was decided that only the first innings would be incorporated, as this would guarantee a ‘complete’ innings hopefully consisting of an adequate amount of time. Thereby, a 3-day match innings could be compared to an innings of a 50 over match and a T20 match. In hindsight, if we wanted to compare overall load between the formats, the second innings should also have been incorporated, thereby having data from a full 3-day match.

Very few data sets were collected for wicket-keepers during the season. So few in fact that the discipline was removed following the statistical analysis. This was due to the fact that the wicket-keeper found the monitoring devices very uncomfortable. Player comfort was of the utmost importance for the coach and, therefore, a priority for the researcher of the current study. On this point, a familiarization period for the GPS vests and units as well as the HR monitors would have been ideal in order to give the players time to become comfortable wearing the above mentioned items.

For the current study, total distance was analysed and not distance per minute. As a result it was not possible to compare intensity per unit of time, between the formats. Due to the lack of data sets from some of the disciplines, it was not possible to perform comparisons between disciplines for the formats. It was possible to compare formats and disciplines separately, as was done in the study, but it was not possible, for example, to compare the loads of fast bowlers during T20 matches to the loads of fast bowlers in 3-day matches. Instead the disciplines had to be grouped as a team, therefore team load was compared between the formats. It would be ideal to compare the load placed on each discipline during each format as this would be discipline specific and have a better influence on training periodization and session planning.

Future studies could:

- Correlate injuries to load over a season
- Compare discipline specific loads across the formats (e.g. load of fast bowlers during T20 matches and 3-day matches)
- Compare training loads to match loads

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APPENDIX A: CONSENT TO PARTICIPATE IN RESEARCH

STELLENBOSCH UNIVERSITY
CONSENT TO PARTICIPATE IN RESEARCH

Match Workloads of Semi-professional, South African Cricket Players over a Competitive Season

You are invited to participate in a research study conducted by Bradley Nell (MSc Sport Science) from the Department of Sport Science at Stellenbosch University. The results obtained from the study will contribute to the thesis for my MSc degree in Sport Science. You were selected as a possible participant in this study because you are a member of the Western Province First Class Cricket Squad for the 2014/2015 season.

1. AIM OF THE STUDY

The primary aim of this study is to monitor match loads, as well as the recovery and fatigue, of semi-professional cricket players over a competitive season.

2. PROCEDURES

If you volunteer to participate in this study, I would ask you to help with the following:

Anthropometric measurements. Allow the researcher access to height and weight information gathered by the Western Province First Class provincial coaching staff.

Global positioning system (GPS) data gathering. Allow data to be gathered from you via GPS units for the entire duration of field training sessions and match play. Each GPS unit will be held in place in the upper back region between the shoulder blades by a padded neoprene vest, provided by GPSports.

Individual reaction to training will be recorded using a Training Distress Scale (TDS).

Cortisol and DHEA concentrations will be determined from saliva samples. These samples will be obtained by depositing saliva, through a straw, into a small vial. The samples will be put on ice and frozen until being sent to Synexa Life Sciences for analysis.

3. POTENTIAL RISKS AND DISCOMFORTS

There are no discomforts associated with the data gathering methods used. The GPS units enclosed in neoprene vests should not cause discomfort due to their small size.

The data that will be collected will be used only to monitor injuries and overtraining. It will not affect your chances to be selected for the team.

4. POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

You will not benefit directly from the study.

The study will benefit science and the sporting society. The results will provide coaching staff with the necessary knowledge to provide players with better planned training programmes and training loads specific to their individual needs. This will allow for optimal performance by reducing the risk of under- or overtraining players.

5. PAYMENT FOR PARTICIPATION

You will not receive payment for your involvement in the study.

6. CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Confidentiality will be maintained by means of storing the data on a password-protected personal computer. Only the researcher and study leader will have access to the data. The data will remain anonymous at all times.

If the research paper is published, the data will be reported for the group as a whole.

7. PARTICIPATION AND WITHDRAWAL

You can choose whether or not to participate in this study. If you volunteer to participate in this study, you may withdraw at any time without consequences of any kind. You may also refuse to answer any questions you do not want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise that warrant doing so.

8. IDENTIFICATION OF INVESTIGATORS

If you have any questions or concerns about the research, please feel free to contact:

Bradley Nell (Mobile: 082 929 5439. Address: 6 De Waal Drive, Somerset West; E-mail: 15797503@sun.ac.za), or Prof Ranel Venter (Mobile: 083 309 2894; E-mail: rev@sun.ac.za).

9. RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, contact Ms Maléne Fouché [mfouche@sun.ac.za; 021 808 4622] at the Division for Research Development.

SIGNATURE OF RESEARCH SUBJECT

The information above was described to me by Bradley Nell in English and I am in command of this language. I was given the opportunity to ask questions and these questions were answered to my satisfaction.

I hereby consent voluntarily to participate in this study. I have been given a copy of this form.

____

Name of Participant

____ _______________

Signature of Participant **Date**

SIGNATURE OF INVESTIGATOR

I declare that I explained the information given in this document to ___________________. He/she was encouraged and given ample time to ask me any questions. This conversation was conducted in English.

____ _______________

Signature of Investigator **Date**

APPENDIX C: TRAINING DISTRESS SCALE

Name: ____________________________ Date: ___________________

Please circle the number that accurately reflects how much you have experienced each of the following symptoms in recent times. Although some of the questions might appear similar, there are differences between them, and you should treat each one separately. The best approach is to answer each question fairly quickly. There are no right or wrong answers, and your first impression is usually the most accurate response.

During the past 48h

To what extent have you experienced	**Not at all**	**A little bit**	**Moderate amount**	**Quite a bit**	**Extreme amount**
1. Muscle soreness	0	1	2	3	4
2. Lack of energy	0	1	2	3	4
3. A quick temper	0	1	2	3	4
4. Not being able to remember things	0	1	2	3	4
5. Difficulty falling asleep	0	1	2	3	4
6. Lack of interest in normal daily activities	0	1	2	3	4
7. Loss of appetite	0	1	2	3	4
8. Snappiness with family, co-workers, or teammates	0	1	2	3	4
9. Restless sleep	0	1	2	3	4
10. Not being able to focus and maintain attention	0	1	2	3	4
11. Not being able to eat well	0	1	2	3	4
12. Heavy feelings in your arms and legs	0	1	2	3	4
13. General irritability	0	1	2	3	4
14. Being unusually tired during the day	0	1	2	3	4
15. Mental confusion	0	1	2	3	4
16. Joint stiffness or soreness	0	1	2	3	4
17. Loose bowels or diarrhoea	0	1	2	3	4
18. Insomnia	0	1	2	3	4
19. A feeling that ordinary tasks require extra effort	0	1	2	3	4

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