

PHYSIOLOGICAL DEMANDS DURING RUGBY UNION MATCH AND PRACTICE SESSIONS

RF Smit
Student number: 25072375

Submitted in fulfilment of the requirements for the degree

MAGISTER ARTIUM
(Sport Sciences)

in the

FACULTY OF HUMANITIES
DEPARTMENT OF BIOKINETICS, SPORT AND LEISURE SCIENCES

UNIVERSITY OF PRETORIA

Study leader:
Prof. P.E. Krüger

ACKNOWLEDGEMENTS

I would like to acknowledge the following people who helped to make this study possible:

-  Prof. P.E. Krüger, my study leader for all his guidance and advice.
-  Tuks rugby club and players for participating in the study.
-  University of Pretoria's Institute for Sport Research for the use of their equipment.
-  Family and friends for all their support.

ABSTRACT

TITLE	Physiological demands during rugby union matches and practice sessions
CANDIDATE	RF Smit
PROMOTOR	Prof PE Krüger
DEPARTMENT	Biokinetics, Sports and Leisure Sciences University of Pretoria
DEGREE	Magister Atrium

Research studies indicate that, by determining the physiological load placed on athletes during competitions, it can aid in the development of strength and conditioning programmes, according to the specific demands placed on athletes (Deutch *et al.*, 1998; Kay & Gill, 2004). Physiological data, specifically on rugby union players, are furthermore limited and more information is needed (Banfi *et al.*, 2006; Deutch *et al.*, 2007).

The aim of the study was to investigate the physiological demands of South African male U/21 club rugby players and to establish the correlation between physiological demands experienced during rugby games and practice sessions. Scientific methods to describe physiological demands in sport that are used are heart-rates and blood-lactate measurements (Eniseler, 2005).

A group of U/21 rugby players (n=15) of the University of Pretoria (Tuks) rugby club participated in this study. Components that were tested included blood-lactate concentrations and heart-rates during rugby match and practice sessions. The data of the Tuks U/21 team was statistically analysed with descriptive statistics (means and

standard deviations). Significant differences between match and practice sessions, at a p-value of $P < 0.05$, were determined by a dependent t-test. An independent t-test was used to determine significant differences between the forward and backs group (Thomas & Nelson, 2005).

The results showed that statistically significant differences ($p < 0.05$) were found between mean heart-rate in the rugby match (154.40 ± 13.53) and practice sessions (138.33 ± 4.81). No significant differences were found between peak lactate measurements in the match (5.39 ± 2.44) and practice sessions (4.93 ± 1.83). Between the forward and backs group no statistical significance could be found for average heart-rate and blood-lactate levels in practice sessions and the match. The findings of the present study indicate that rugby union matches for club level U/21 players are an intermittent type of activity, with both the use of aerobic and anaerobic energy systems. Additional research on more amateur rugby clubs is needed to extend the knowledge of club level coaches.

KEY WORDS: Physiology; rugby union; amateur level; game; practice session; heart-rate; blood-lactate; strength and conditioning; coaching; specificity;

OPSOMMING

TITEL	Fisiologiese behoeftes tydens rugby wedstryde en oefensessies
KANDIDAAT	RF Smit
PROMOTOR	Prof PE Krüger
DEPARTEMENT	Biokinetika, Sport- en Vryetydswetenskappe Universiteit van Pretoria
GRAAD	Magister Atrium

Navorsing dui aan dat deur die bepaling van die fisiologiese vereistes op atlete gedurende kompetisie, kan bydrae tot die ontwikkeling van spesifieke krag en kondisionerings programme gebaseer op die fisiologiese druk wat atlete ervaar (Deutch *et al.*, 1998; Kay & Gill 2004). Daar word egter fisiologiese data spesifiek op rugby unie spelers benodig (Banfi *et al.*, 2006; Deutch *et al.*, 2007).

Die doel van hierdie studie is om die fisiologiese druk van Suid-Afrikaanse, onder 21 rugby spelers te ondersoek en om 'n korrelasie tussen wedstryd en oefen sessies op te stel in terme van die fisiologiese druk tydens die twee omstandighede. 'n Wetenskaplike metode om fisiologiese druk te bepaal in sport is deur middel van die meting van hart tempo en bloedlaktaat vlakke geïdentifiseer (Eniseler, 2005).

'n Groep van onder 21 rugby spelers (n=15) van die Universiteit van Pretoria (Tuks) rugby klub, het deelgeneem aan hierdie studie. Komponente wat getoets was het hart tempo en bloedlaktaat vlakke tydens wedstryd en oefen sessies ingesluit. Die data van die Tuks spelers was statisties geanaliseer met beskrywende statistiek (gemiddeldes en standaardafwykings). Betekenisvolle verskille was bepaal teen 'n p-waarde van $P < 0.05$, deur middel van die t-toets vir afhangklike groepe vir die bepaling van verskille tussen wedstryd en oefen sessies en die t-toets onafhanklike groepe, vir die bepaal van verskille tussen voor-en agter spelers (Thomas & Nelson, 2005).

Die resultate van die studie het getoon dat statistiese betekenisvolle verskille gevind is vir die gemiddelde hart tempo (in slae per min) in die rugby wedstryd (154.40 ± 13.53) en oefen sessies (138.33 ± 4.81). Geen betekenisvolle verskille vir bloedlaktat vlakke tydens wedstryd (5.39 ± 2.44) en oefen sessies (4.93 ± 1.83) is gevind. Tussen die voorspeler en agterspeler groep is daar egter ook geen betekenisvolle verskille gevind vir beide hart tempo en bloedlaktat vlakke.

Die bevindinge van die huidige studie dui aan dat rugby unie wedstryde op onder 21 klub vlak 'n intermidiêre tipe aktiwiteit is wat beide die aerobiese en anaerobiese energie sisteme van die spelers benodig. Addisionele navorsing op amateur rugby klubs word benodig om die kennis van klub vlak afrigters uit te brei.

SLEUTELTERME: Fisiologie; rugby unie; amateurvlak; wedstryd; oefenensie; harttempo; bloedlaktat; krag en kondisionering; afrigting; spesifisiteit

LIST OF TABLES

Table #	page #
Table 2.1: Mean distances covered by the four positional groups	22
Table 2.2: Estimates of anaerobic and aerobic energy contribution during selected periods of maximal exercise	25
Table 2.3: Position-specific ergogenesis	26
Table 2.4: Incidence and severity of injuries as a function of playing position, activity, and phase of preparation for the Rugby World Cup	39
Table 2.5: Six week speed and agility conditioning example	58
Table 2.6: The four intensity zones for rugby	66
Table 2.7: Using interval training to train specific energy systems	67
Table 4.1: Descriptive statistics for Tuks under 21 rugby players in terms of heart-rate and blood-lactate concentrations during different activities	83

LIST OF FIGURES

Figure #	page #
Figure 2.1: Mean blood-lactate concentration during a semi-professional rugby league match.	76
Figure 3.1: Hosand®, TM 200 real time heart-rate monitor system	79
Figure 4.1: Heart-rates during rugby match and practice sessions	87
Figure 4.2: Peak blood-lactate levels during practice sessions and the rugby match	89

TABLE OF CONTENTS

	PAGE #
ACKNOWLEDGEMENTS	i
ABSTRACT	ii
OPSOMMING	iv
LIST OF TABLES	vi
LIST OF FIGURES	vii
CHAPTER 1	
RESEARCH PROBLEM AND GOAL OF STUDY	
1.1 Introduction	1
1.2 Research problem	9
1.3 Literature review	10
1.4 Relevance of and motivation for the study	11
1.5 Research hypothesis	12
1.5.1 Goal and objective of the study	12
1.6 Methodology	13
1.6.1 Research design	13
1.6.2 Type of research	13
1.6.3 Problem analysis and project planning	14
1.6.4 Sampling	15
1.6.4.1 Target population	15
1.6.4.2 Sampling method	15
1.6.4.3 Sample size	15
1.6.5 Measurements	15
1.6.5.1 Heart-rate	15
1.6.5.2 Blood-lactate measurement	16
1.6.6 Data collection & analysis	16
1.6.6.1 Procedures and research methods	17
1.6.6.1 Statistical data processing	18
CHAPTER 2	
LITERATURE REVIEW	

2.1	Introduction	19
2.2	History on conditioning in rugby	19
2.3	Work intensities of rugby	21
2.4	Energy systems used in rugby	24
2.5	Training principals of rugby	27
2.5.1	Specificity	27
2.5.1.1	Position specific conditioning	29
2.5.1.2	Position specific rehabilitation of injuries	33
2.5.2	Overload	35
2.5.3	Periodisation	37
2.5.4	Recovery	43
2.5.5	Overtraining and injuries	47
2.5.6	Fatigue	52
2.6	Training of the alactic and lactic acid system	55
2.6.1	Speed training	56
2.6.2	Resisted speed training	59
2.6.3	Speed assessment	60
2.7	Training of the aerobic system	61
2.7.1	Aerobic energy system assessment	63
2.8	Combination training for all energy systems	65
2.8.1	Interval training	66
2.8.2	Tempo training	69
2.8.3	Anaerobic energy system assessment	70
2.8.4	Heart-rate as an indicator of the physiological demands of exercise	71
2.8.5	Blood-lactate concentrations as an indicator of the physiological demands of exercise	73
 CHAPTER 3		
METHODOLOGY		
3.1	Introduction	77
3.2	Study population	77

3.3	Test protocol	77
3.3.1	Practice session	77
3.3.2	The match	78
3.3.3	Heart-rate	78
3.3.4	Blood-lactate concentration	79
3.3.5	Statistical analysis	80
CHAPTER 4		
RESULTS AND DISCUSSION		
4.1	Introduction	82
4.2	Physiological data of the Tuks rugby club players	82
4.3	Conclusion	91
CHAPTER 5		
CONCLUSIONS AND RECOMMENDATIONS		
5.1	Introduction	93
5.2	Conclusion	93
5.2.1	Limitations of the study	94
5.3	Recommendations	95
REFERENCES		97

CHAPTER 1

RESEARCH PROBLEM AND GOAL OF STUDY

1.1 INTRODUCTION:

Literature on physiological aspects and demands of different sporting codes has been extensively researched, as numerous studies have been conducted on it, specifically using heart-rate and blood-lactate data. Jeukendrup and Van Diemen (1998) measured heart-rate during training and competition in cyclists. As speed is not the best way to monitor exercise intensity in cycling, alternatives were tested. The findings of the study were that heart-rate monitoring can be used to monitor cyclists after training and competition, as well as to detect overtraining. Smith (1998) did a review article on applied physiology of waterpolo players, where he indicated that the use of heart-rate monitoring and capillary blood-lactate analyses have previously been used in the sport to determine metabolic and cardiovascular demands of the game activities. Guevèl *et al.* (1999) measured heart rate and blood-lactate during various competition events of Olympic boardsailing to determine metabolic and cardiac responses of the athletes. The study indicated that sailboarders must train to endure 35-minute sessions of high-intensity exercise during competition sailing. Noakes and Durandt (2000) did a review article on the physiological aspects of cricket players and it was stated that cricket players have the same fitness levels in terms of anaerobic power and aerobic endurance, although heart rate and blood-lactate concentration levels are lower during cricket matches. Unfamiliar sports have also received some attention by researchers, as Warrington *et al.* (2001) determined physiological and metabolic characteristics of elite tug-of-war athletes through the use of a laboratory testing protocol. The study indicated that tug-of-war athletes' have an above-average aerobic power for the athletes' body size. Aziz *et al.* (2003) determined the profile of Sepaktakraw (a sport similar to badminton) players, which included heart rate and blood-lactate level measurements during matches.

Chatterjee *et al.* (2005) created a physiological profile for Indian women boxers through measuring the heart rate and blood-lactate response of 20 female boxers between the ages of 17-24 years during sparring boxing sessions. The study concluded that boxing is a highly intensive intermittent sport involving high demand of glycolytic anaerobic metabolism. Bouhlel *et al.* (2006) studied Taekwondo athletes' physiological profiles by identifying differences between competition and training in terms of heart-rate and blood-lactate concentrations. The results of the study indicated that a Taekwondo athlete requires a combination of physical fitness to compete in the sport. Tessitore *et al.* (2006) did a research study on old, senior basketball players where data of heart-rate, blood-lactate and motor activities was recorded from the players during a basketball match. This data, together with the results of other scientific sport tests, was used to compile aerobic-anaerobic profiles of the senior basketball players. Baillie *et al.* (2007) examined Highland dancers during competition and normal dance classes, where it was determined that, during competitions, heart-rates were much higher than during the classes.

Kovacs (2007) used physiology data to explain how to train tennis players, while D'artibale *et al.* (2008) compiled, in a study, a physiological profile of road-race motorcycle riders, using heart-rate data and blood-lactate concentration data. It is interesting to note that peak blood-lactate concentrations were slightly higher after the official races than after the qualifying sessions, and that road race motorcycle riders should have some fitness to counter the effect of fatigue in competitions. Durocher *et al.* (2008) tested ice-hockey players to come to the conclusion whether aerobic capacity, as well as skating velocity at lactate threshold, will increase as the hockey season progresses. The testing took place during practice sessions, where heart-rate, blood-lactate and skating-speed velocity were measured. Ghosh (2008) measured heart-rate and blood-lactate of badminton players while the players executed different type of strokes played in this type of racquet sport. The researcher concluded that the strokes played in the sport of badminton places a considerably high metabolic load on players and therefore a well developed cardiovascular fitness is needed. Farrow *et al.* (2008) investigated the skill and physiological demands of open- and closed practice drills which are used in

Australian football. The physiological responses of players were assessed with heart-rate, blood-lactate concentrations and a Rate of Perceived Exertion (RPE) scale. The conclusion of the study was that performing open drills in practices can contribute to a better physical and cognitive training session for players.

Veale and Pearce (2009) determined physiological responses of junior Australian-rules players by measuring heart-rate, blood-lactate, core temperature and hydration status during matches in an U/18 competition. In the sporting code of soccer, which is classified as the same type of activity intensity as rugby, the physiological demands of the game have been researched thoroughly. Ekblom (1986) examined soccer player's physiological characteristics in the game situation. The distance travelled during a game by means of a time-motion analysis study was determined, along with testing of the blood-lactate levels of the players. Maximal aerobic power, muscle strength and flexibility in the study were determined through laboratory tests. Davis and Brewer (1993) detected that there was a lack of research in the physiological demands of women soccer players. The study indicated that game demands placed on women players were similar to male players in terms of aerobic and anaerobic energy system usage. Ostojic (2000) specifically determined physical and physiological features of elite and amateur Serbian soccer players. The physiological characteristics were determined by field tests in the last week of the preparatory training phase. Heart-rate in the study was measured during the 20m-shuttle run test and it was established that elite players had a lower heart-rate response during the last minute of the test than the amateur players. Eniseler (2005) investigated heart-rate and blood-lactate concentrations of elite soccer players, the physiological strain during different soccer training activities, as well as during friendly soccer matches. The study gave guidelines between which heart-rate zones players should ideally train to be optimally prepared for soccer matches. In the study by Reilly (2005), an ergonomic training model is described that made use of previous studies that focused on fitness profiles of players and physiological demands of soccer. It was further noted in the study that regular monitoring of the work rates and physiological responses of players during matches are important for the purpose of creating match intensities during practice sessions. Tessitore *et al.* (2005) evaluated

older soccer players (mean age 62 years) during laboratory tests and a match by measuring heart-rate and blood-lactate concentrations, to create an aerobic and anaerobic profile of these players. The study concluded that older soccer players still have a fair amount of aerobic and anaerobic fitness.

Drust *et al.* (2007) indicated future perspectives in the evaluation of the physiological demands of soccer. The study included the determination of physiological requirements of soccer players using measurements such as heart-rate, muscle biopsies and blood samples during matches. Little and Williams (2007) used blood-lactate and heart-rate in professional soccer players to examine the physiological effects of different repeated sprint exercises on these athletes. Results of the study indicated that sprinting activities over 15m and 40 m, with the same work-to-rest ratio produced similar blood-lactate and heart-rate responses.

Jones and Drust (2007) used heart-rate and work-rate profiles of specifically elite youth soccer players to determine whether the number of players per side in small-sided soccer games had an influence on the physiological demands placed on the players. The result of the study indicates that the number of players in a match is not an influential determinant of the demands placed on players. Williams and Owen (2007) examined senior soccer players and the impact of the number of players on physiological responses in small-sided soccer games that were played. The average heart-rate was used with recording intervals of 5 seconds, with the result being that the number of players playing does not change heart-rates.

Another study by Rampinini *et al.* (2007) also focused on small-sided soccer games, where they used heart-rate, blood-lactate and a RPE scale as indicators of physiological responses to a variety of these small-sided soccer games for amateur soccer players. It differed in field dimensions, exercise type and verbal motivation of the coaches versus no motivation. The results of the study indicated that a 3-a-side soccer game, on a large field of 18x30m and with the coaches' encouragement, elicited the highest physiological response from the players. It was further concluded that the aerobic intensity level

during these small-sided soccer games can be altered by the above mentioned factors. Barbero-Alvarez *et al.* (2008) also used heart-rate in determining match activities and intensities of 5-a-side indoor soccer players and indicated that football players tend to complete high-intensity sprint phases, higher than in normal soccer matches.

A study by Coutts *et al.* (2009) on players participating in small-sided soccer games indicated that a combination of heart-rate and blood-lactate measurements is better related to the RPE scale than separate heart-rate and blood-lactate measurement.

Some scientific review articles on physiology in soccer have also been published. Stolen *et al.* (2005) discussed many aspects of the physiology in soccer, which included physical demands of the game and physiological profiles of players and referees, as well as training aspects and testing protocols. Krstrup and Bangsbo (2001) also did a study on soccer referees, included time-motion analyses, laboratory testing, which included the Yo-Yo intermittent recovery test and measuring heart rate, as well as the measurement of blood-lactate concentrations. The findings of the study concluded that match performance was related to the physical capacity of the soccer referees. Castagna *et al.* (2007) specifically reviewed physiological aspects of soccer refereeing performance and training, while Krstrup *et al.* (2009) examined international referees and assistant soccer referees during matches. An activity profile of soccer referees was compiled in the study with the information that was obtained from measurements of heart rate and blood-lactate, as well as analysis from video footage that was taken of the referees.

Rugby literature

In the study of Kay and Gill (2004), heart rate of referees was measured to determine the physiological demands on them. The findings of the research demonstrated that refereeing is a highly-intermittent intensity activity that needs specific training to reflect the demands referees experience during games. Rugby league is a similar sport to rugby union, but is played in a format where a team consists out of thirteen players. The rules are different, but match duration is the same as rugby union, two 40-minute

periods, separated by a 10-minute rest interval (Brewer & Davis, 1995; Gabbett *et al.*, 2008).

Numerous studies on physiological aspects of rugby league were also done. Gabbett (2000) investigated physiological and anthropometric characteristics of amateur rugby league players using physical tests, such as a vertical jump test, 10-and 40 m sprint test, as well as the multistage fitness test. The conclusion the study came to was that amateur players had poorly developed fitness, which may be due to lower intensities during matches and not enough training. Gabbett (2002a) examined the influence of the physiological characteristics of players on the selection process of coaches for selecting a semi-professional team and indicated that players' body mass, skill and experience had more influence on the player selection.

Another study by Gabbett (2002b) investigated the physiological characteristics of junior and senior sub-elite rugby players by using field tests to determine the difference between players who were in the starting team and the team substitutes. The results indicated that elite players had superior physical qualities to the substitutes, which include height as well as weight, while at sub-elite level, starters were the fastest and had greater change of direction and speed. Coutts *et al.* (2003) researched heart-rate, blood-lactate and estimated energy expenditure during competitive semi-professional rugby league matches. The researchers used the data to emphasize the fact that rugby league is a combination of an aerobic and anaerobic type of game, which requires players to have a high lactate tolerance. The physical demand of referees in rugby league has also received some attention. Gabbett (2005b) used physiological and anthropometric data to determine whether there are differences between the playing positions in junior rugby league players and came to the conclusion that only a few differences exist in terms of length, height, skinfold thickness, speed and anaerobic power.

Gabbett (2005c) also examined changes of physiological characteristics of amateur rugby league players during a whole competitive rugby season and found that there was an increase in muscular power and a reduction in body fat percentage. The speed of the

players remained constant for most of the season. Gabbett (2006) furthermore used physiological and anthropometric characteristics to compare sub-elite rugby league players to determine if differences exist among playing positions. Even female rugby league players have received some attention as Gabbett (2007) determined physical performance standards by means of physiological and anthropometric characteristics of the players. The findings suggested that development of the physiological tolerance of female rugby league players needs to be increased. King *et al.* (2009) recently have done a review article on all published data on rugby league players' physiological characteristics who participate on various levels, indicating that match intensities increase as playing level increase.

Currently, according to the researcher literature review, insufficient research material exists on detailed assessment of the physical demands of rugby, specifically on amateur- and club level rugby. As indicated in the literature survey, many studies have been done on elite rugby players by investigations on the movement patterns during match play, physiological measurements taken during a match or simulated match play, and the assessment of physiological capacities (Duthie *et al.*, 2003). However, despite these studies, Banfi *et al.* (2006) and Deutch *et al.* (2007) indicate that there is still a lack of information on the physiological demands of professional rugby union. One of the earliest studies on rugby union's physiological aspects of the sport was conducted by Morton (1978). He applied physiological principles to rugby training after studying international and regional rugby matches.

Another of the early studies on physiological demands of rugby was done by Maud (1983). The research study was done on a United States of America (USA) amateur rugby union club to describe the teams' physiological and anthropometric characteristics. The physical tests were all done in a laboratory setting. Another study that focused on USA rugby players was done by Maud and Shultz (1984). The study did a physiological and anthropometric assessment on elite players. A comparison was then made between the rugby players' data and other elite athletes of other sports. The conclusion the study came to was that ice hockey and soccer players had higher aerobic

fitness than the rugby players. Mclean (1992) did an analysis of the physical demands of international rugby union players that included a time-motion analysis and the measurement of blood-lactate concentration during a rugby match. The study also indicated that rugby players' must rely more on their anaerobic glycolysis an energy systems which was reported otherwise in other studies.

A review article by Reilly (1997a) on the physiology of rugby union agrees that the anaerobic component of the game is important as it relates to performance on the field. A scientific approach to training is required for players to compete in the professional era of rugby. Deutch *et al.* (1998) researched U/19 elite rugby players. In their study heart-rate, blood-lactate and kinematic were gathered to get more insight on the physical demands of rugby union. It was established that the aerobic and lactate energy systems are an important component of conditioning as it contributes to overall match fitness.

Doutreloux *et al.* (2002) used heart rate, together with video analysis, to determine the energy requirements of rugby players during a rugby union game. The energy demand of each playing position was determined in the study, which indicated that forward players use the lactic acid energy system more, while backline players tend to use the alactic energy system. Maso *et al.* (2002) determined physiological features of French rugby teams by means of physical tests. They concluded that forwards and backs differ in morphological and metabolic plane, as well as in power and suppleness. Several studies were also done on the biochemical indices in rugby union players to better understand the physiology aspect of the game (Mellalieu, 2008). Mashiko *et al.* (2004b) used blood biochemical parameters, such as hematocrit and white blood cell count, of 37 university rugby players to determine if a difference in physical and mental fatigue exists after a match between forward and backline players, and found that there may be a difference in physical and mental fatigue, according to the position they play.

Banfi *et al.* (2006) assessed heamatological parameters by taking blood samples during a whole competitive rugby season to gain information on the physiological aspect of rugby, specifically examining haematological parameters. It was found that haemoglobin

and haematocrit levels were lower towards the end of the season. Elloumi *et al.* (2008) researched psycho-endocrine and physical performance responses in male Tunisian rugby players during an entire rugby season. The study measured biological markers such as the plasma concentration levels of free Testosterone and Cortisol of players. One of the conclusions the study came to was that the Testosterone to Cortisol Ratio (T/C ratio) increases when matches are highly competitive. The T/C ratio can be used as an indication of the tiredness of players with an increase in training load.

This project will use the measurement of heart-rate and blood-lactate to help establish some physiological demands of club rugby on under-21 male players of the University of Pretoria Rugby Club. By measuring heart-rates and blood-lactate, coaches and researchers can estimate the physiologic load on individual players in an objective way (Eniseler, 2005). It can thus provide important feedback to coaches and trainers regarding the training stimulus applied to the players and an effective training programme can assist in the success of a team (Brooks *et al.*, 2008). According to Borresen and Lambert (2008b), exercise programme can also be developed from the information obtained through the measurement and monitoring of training loads.

The research data of this study will therefore provide coaches with the necessary information to construct up to date training programme to stimulate or overload physiological rugby game conditions, without overtraining players. The aim of the study is therefore to establish the relationship between physiological demands experienced during rugby games and practice sessions.

1.2 RESEARCH PROBLEM:

Rugby is an internationally-known sport which is competitive on all levels of participation. According to Mellalieu (2008) editorial review, previous research in rugby physiology covered a wide range of factors and has provided useful information on the physiology of a rugby player, but almost no study has looked at the heart-rate and blood-lactate concentration response of under-21 rugby players during matches and practice sessions. He further concludes that more controlled interventions are needed to

find the best way to prepare players for matches by further understanding the demands of the game. Elloumi *et al.* (2008) also express the need to improve the performance of players by applying the correct volume, intensity and overall workload in practice sessions for positive physiological adaptation to occur without overtraining the players.

This study may create a more accurate and controlled environment for measuring physiological responses and adaptations during matches and practice sessions. Most of the studies referred to by Mellalieu (2008) were furthermore done on elite rugby players. The conclusion of the researcher's literature review indicates that insufficient scientific research in rugby exists on club level. Extra information on club players is thus necessary in rugby physiology to condition players optimally for physiological demands during club rugby matches. Profiling studies have been previously used in other sports to develop normative data (Chaouachi *et al.*, 2009).

This study aims to collect more information in the physiological aspect of rugby through monitoring heart-rate and blood-lactate concentrations during a match and practice sessions. The relationship between the two conditions (during a match and practice) can also serve as an indication of players' optimal use of sessions to improve their fitness.

The research problem can be summarised as the need for more data on the physiological aspect of rugby on club level to develop and implement a sport-specific conditioning programme according to match requirements.

1.3 LITERATURE REVIEW:

A literature study was done to give this study a theoretical background base to work from. A clear understanding of the game of rugby, as well as how to prepare players for the game is needed before this study can be done. Areas that were therefore focused on in the review of the literature included the demands of playing rugby and training for the game, as well as which indicators can be useful to indicate intensity and demands of exercise in general. The review of related research assists the study by giving insight into the reasoning and necessity of the study. It further provides information on data that

can be linked to this study for comparison. The full literature review can be seen in chapter two.

1.4 RELEVANCE AND MOTIVATION FOR THE STUDY:

Rugby is a competitive and specialised sport in most countries of the world. The development of academic study in rugby union is behind when compared to other sporting codes and more scientific-based rugby research can help aid in the development (Mellalieu, 2008).

The latest research done on rugby in the sub-discipline of physiology is mostly based on elite rugby players. The development of club rugby is just as important, because recruitment of national players comes in most rugby playing countries from club teams. Rugby can also always improve as a sport to improve the game; rugby players must better themselves through the use of correct and up to date conditioning training methods that are based on the scientific knowledge of the game (Craven, 1970). In South Africa, club rugby also plays an important role, as provincial teams recruit their players from clubs. Some highly-competitive club competitions are held every year, e.g. the National club championship. Locally in Pretoria, South Africa, in the Blue Bull Carlton league (Club competition for teams of the Gauteng North province) there is a big gap among participating teams in terms of performance on the field, as some teams are dominating the league.

If a conditioning model for fitness can be created for club rugby players, improvement of the fitness element can contribute to minimising the aforementioned gap. As Gabbett *et al.* (2007) states, high physical fitness of the players can positively contribute to the effectiveness of the playing ability of rugby players. Lastly, this study can also contribute to improve the overall fitness standard of club rugby in South Africa by fully developing the players' potential, giving them the necessary resources for optimal use in match preparations.

The study will therefore focus specifically on club rugby union players and some physiological strain experienced by them during practice sessions and a rugby match. This can help strengthening and conditioning coaches to gain information about some of the metabolic conditions present in players during practice and match circumstances. This information retrieved from the study can be used to develop specific exercise conditioning programme for club players to optimally prepare them for match conditions as sport-specific conditioning is a scientific way of stimulating metabolic conditions encountered by players during competition (Gamble, 2004b).

By the measuring heart-rate and blood-lactate concentrations during matches and practice sessions in the study, the overall physiological load on club rugby players can also be determined. This is a good indication of the typical intensity demands of rugby union on club level during a match and training, using heart-rate and blood-lactate as indicators.

1.5 RESEARCH HYPOTHESIS

The two research hypotheses of the study are as follows: Heart rate and blood-lactate concentrations are lower during practice sessions than in a rugby match. Forwards and backline players' physiological data differ during a rugby match.

1.5.1 GOAL AND OBJECTIVE OF THE STUDY

1.5.1.1 Goal:

The goal of the research study is to determine if heart-rates and blood-lactate concentrations of club rugby players are the same during rugby matches and practice sessions.

1.5.1.2 Objectives:

Objectives to be obtained by the research study are:

- To determine if there is a significant difference ($p < 0.05$) between heart rate and blood lactate during a match and practice sessions.

- The evaluation of whether team practice sessions provide enough stimuli to prepare players for matches.
- Compare physiological stress placed on forwards and backline players in matches and practices.
- To determine if there is significant differences ($p < 0.05$) between the two different circumstances (practices and match) for forward- and backline players in terms of average heart-rate and peak blood-lactate concentrations.

1.6 METHODOLOGY

1.6.1 Research design

A combination of qualitative and descriptive research methods will be used in this study. Descriptive research is used in qualitative research to deal with critical problems and to extend the knowledge base of various aspects of physical education, exercise science and sport science (Thomas & Nelson, 2005). The descriptive research method of the case study will be used specifically.

1.6.2 Type of research

The type of research that the researcher will use in this study is qualitative research. In qualitative research, the researcher is the primary instrument for data capturing and analysis (Thomas & Nelson 2001). With qualitative research, there is not an excessive concern with the procedure in the study, but there is more focus more on the interpretive content of the study (Thomas & Nelson 2001). In the study, the researcher will interact with the single group participating in the study, observing and processing responses in an objective manner.

Another type of research that is applicable and will be used in this study is descriptive research in the form of a case study. The case study is an in-depth understanding of a single situation or phenomenon of an individual or group (Hyllegard *et al.*, 1996; Thomas & Nelson, 2005). The case study, as another form of research, involves the identification of the problem and collection of data and analysis, together with the reporting of results

(Thomas & Nelson 2001). The case study is furthermore used to provide detailed information about an individual or community and also aims to determine unique characteristics about the subject or condition (Thomas and Nelson 2001). In this study, detailed information on under-21 rugby players will be given.

1.6.3 Problem analysis and project planning

According to De Vos (1998), there are two factors involved in identifying a condition as a problem:

- Recognition that professional and/or community standards (or norms) exist ~ based on social values that define given levels of behaviour or well-being as appropriate; and
- Discrepancies between the standards or norms and the existing behaviour or states of wellbeing of given individuals or groups.

A problematic human condition can be identified through problem analysis that precedes the development of technology to address it. Such analysis consists of determining one or more of the following (De Vos, 1998):

- The extent of the difficulty, such as its incidence or prevalence;
- The component aspects of the problem;
- The possible causal factors;
- The effects of the problem including the behavioural, social and economic accompaniments; and
- Intervention shortcomings in how the problematic conditions are confronted.

The next phase in this step is to determine the procedures of the intervention. It is necessary to determine whether relevant interventions already exist and, if so, whether further development is merited (De Vos, 1998). Intervention that will be used in the study is by means of creating an exercise programme according to the data that is collected through physical testing.

1.6.4 Sampling

1.6.4.1 Target population

The target population will include male rugby players part of the U/21 rugby teams of the University of Pretoria.

Particular attention will be given to players who are regularly chosen to play for the teams, as they are the best players to be on form.

1.6.4.2 Sampling method

The sampling technique that will be used is the sample of convenience. A convenience sample indicates the individuals who are easiest to reach, or where sampling can be done in the easiest way (Thomas & Nelson, 1996). The sample will be confined to representatives of the U/21 rugby team squad of the University of Pretoria. The regular starting fifteen players will be primarily used for the study to accurately determine the relationship between variables in matches and practice sessions.

1.6.4.3 Sample size

The sample size will consist of the 15 rugby players who play in a particular rugby match. The intention is to obtain information from several players to get an average of the two variables that will be tested.

1.6.5 Measurement

1.6.5.1 Heart rate

Heart rate will be a good indicator of intensity during the physical activity of players, as a linear relationship exists between heart-rate and work rate (Deutch *et al.* 1998).

Vuori (1998) indicates that heart-rate monitors can aid in an accurate, reliable assessment of cardiac strain and intensity of a physical activity. Terbizan *et al.* (2002) agree on the fact that heart-rate monitoring can aid in the measurement of heart rate and at the same time apply the right heart-rate intensity for a specific exercise. Aubert *et al.* (2003) recommends that research using heart-rate data which relates to exercise physiology must include descriptive information on the training program together with

the duration and intensity of exercise for accuracy of the research. Maximal heart rate is furthermore specific to the mode of exercise and obtaining the actual maximal heart-rate during a maximal exercise test is the preferred method (Whaley, 2005).

Heart-rate monitors measure the heart-rate response to the exercise. Heart-rate telemetry monitors with chest electrodes proved to be accurate for measuring heart rate (Leger & Thivierge, 1988). Maximal heart rate is the highest heart-rate recorded, which is best determined during maximal effort exercises (Pettitt *et al.*, 2007). In this study heart-rate will be determined during training and match situations.

1.6.5.2 Blood-lactate measurement:

Field-based tests using blood-lactate response to exercise is very specific to actual athletic performance and the way blood-lactate levels change due to the balance of lactate production and elimination from the blood during exercise. It can also give an indication of the player's adaptation to training (Bourdon, 2000; Drust *et al.*, 2007).

Hoff and Helgerud (2004) support the fact that lactate response can be a high-quality indicator of training-induced adaptations to the cardiovascular system. In the present study, a portable blood-lactate analyser will be used to analyse blood samples taken from the ear lobe of the players before, during half-time and after the rugby match. The whole process of measuring blood-lactate is more accurate these days with the automated lactate analysers that offer easy sampling to researchers (McLean *et al.*, 2004).

1.6.4 Data collection and analysis

The majority of the data is collected from the physical testing that was done by the researcher. The comparison was made for the two variables (heart-rate and blood-lactate concentration) in the two different circumstances (during a match and practice sessions). The data collected from the Tuks rugby team was statistically analysed with descriptive statistics (means and standard deviation).

1.6.6 Procedures and research methods

The protocol was approved by the Post-graduate Committee and the Ethics Committee of the Faculty of Humanities at the University of Pretoria. Each individual participated in the research project from their own free will. It was explained to all participants that all the information and data will be handled confidentially and will also be applied if the research should be published. No information will be published without the necessary consent or approval of the participants. It will not include any information that could identify any individual.

All the participants in the research study had to complete an Informed Consent and Indemnity form. All the participants have signed the Informed Consent and Indemnity form, giving authority to the researcher to use the data for research purposes. All the data will be used and reported in such a way that the participant remains anonymous. Efforts were made to ensure participant privacy. The testing procedures were fully explained beforehand and on the day of testing. The investigator was willing to answer all queries about any unclear procedures (Thomas & Nelson, 2001). Nothing was done that would frighten, embarrass or cause harm to the participants during the study. The risks involved in participating in the study included all the normal risks of participating in the contact sport of rugby union.

Approval was been granted by the University of Pretoria Rugby Club and the participants; the evaluation process of players took place at training sessions and one of the Tuks under-21 rugby matches. Measurements were done by qualified personnel who are trained to use the equipment for testing purposes.

The rugby game was approached as a normal rugby game. Before warm-up for the game took place, blood-lactate concentration measurements of the players were done, as well as the measurement of the resting heart rate of the players. During the game players' heart rates were constantly monitored and blood-lactate measurements of some players were taken during half- time and also at the end of the match.

1.6.6.2 Statistical data processing

The data of the Tuks rugby players was captured on Excel and analysed by the SAS-computer program (Version 9.2). Statistical data analysis procedures that were used in the study included descriptive statistics (means and standard deviations) to describe the data and inferential statistics to determine significant differences.

These significant differences were determined by both a dependent and independent t-test. The dependent t-test tests whether a significant difference exists between means scores of two sets of scores which are related, where subjects are tested twice on the same variables (Thomas & Nelson, 2005). In an independent t-test, tests differ between two samples of data (Thomas & Nelson, 2005). Significant differences in the study were determined between the two different circumstances (practice and match) for the entire team and forward- and backline players in terms of average heart-rate and peak blood-lactate concentrations. The significant differences were reported at a p-value of $P < 0.05$.

CHAPTER 2

LITERATURE REVIEW:

2.1 INTRODUCTION:

This chapter of the study will focus on different aspects of rugby in terms of the fitness and conditioning aspects of the sport. The chapter begins with a short historic background on conditioning in rugby. Other topics that will be discussed include demands of the game, fitness training for rugby and indicators of the physiological demands of exercise.

2.2 HISTORY OF CONDITIONING IN RUGBY:

Archives of fitness and physical training for rugby in South African literature have existed for many years as Craven (1966) already published a book in which he described that fitness is an important component for playing rugby. However, the necessary attention was not given to it in those years. Craven (1970) also described in another book some physical and fitness preparation exercises for rugby, which included lifting stones for the physical aspect of the game, isometric exercises and running programme which incorporated stamina and speed.

Internationally, Morton (1978) published one of the first studies on physiological aspects of rugby union and from this study he developed a total all-year round training programme for rugby players. His fitness programme focused on the interval nature of the game of rugby. In the 1980,s more books on rugby as a sport were published, with some reference to fitness for rugby. Carwyn (1983) stated that physical conditioning for rugby is fundamental and a top fitness level is required to perform on the field. The conditioning coach and coach must try to maximise the difference gap between fatigue and peak fitness. He further mentioned that monitoring players must be done in a laboratory setting with scientists experienced in athletic monitoring, but Britain at that time had a lack of such facilities.

Davis and Ireland (1985) also suggested that fitness of speed, stamina, strength and suppleness can add to mental discipline and hardness of players. Noakes and Du Plessis (1996) indicate in their book that one of the first people to newly emphasize the global fact that fitness may benefit rugby players is Jim Blair from New Zealand. According to Blair (1990) in Noakes and Du Plessis (1996), the type of fitness training programme by Blair was based on the physical characteristics that players experienced during a game. Noakes and Du Plessis (1996) indicate that the implemented fitness programme of Blair undertaken by the New Zealand side for the preparation of the 1987 World Cup, may have contributed to their win of the World Cup. As Davies and Eales (2003) also describe in their book, the All Black team of 1987 were physically strong and far ahead of other teams.

The England's side was also very successful in their 1991 and 1995 World Cup campaign, coming second and third respectively. It is speculated that the national fitness programme initiated by Don Rutherford (technical advisor of England's Rugby Union 1989-1995) led to this success (Hazeldine & McNab, 1991; Davies & Eales, 2003). Dwyer (1992) in Noakes and Du Plessis (1996) also mentions the scientifically-based preparation programme that elite Australian players followed in 1989, which could have contributed to Australia winning the 1991 Rugby World Cup. The training programme consisted of fitness and power exercises, nutrition and analysis of individuals' playing patterns, and weaknesses were also added.

After South Africa's return to international rugby in 1992, the unfitness of the South African international team came under the attention of the rugby world. Provincial players generally did not pay enough attention to training for fitness conditioning before 1989, despite previous published books on rugby. Noakes and Du Plessis (1996) refer to one of the conditioning programmes done under Victor Vass (an athletic coach), appointed by Ian MacIntosh, coach of the 1987 Natal provincial rugby team. It consisted of sprints on the track, plyometrics and exercises to increase leg power.

In 1990, Natal won the Currie Cup (local South-African provincial rugby championship) for the first time in 100 years. According to Noakes and Du Plessis (1996), the conditioning programme of their fitness specialist, a biokineticist named Richard Turnbull, may have contributed to this win. Rugby playing provinces in South Africa have since then given the necessary attention to fitness.

The training of players is constantly changing with new methods of conditioning; this may lead to changes in player characteristics, as well as match activities (Quarrie and Hopkins 2007). Due to the competitive nature and law (rule) changes in rugby, the demands of the game are furthermore becoming more complicated because of the large multiplicity of movement patterns of players on the field (Jougla *et al.*, 2009). It will thus be meaningful for strength- and conditioning coaches of rugby teams to monitor the degree of influence and change to apply and adapt their training programme accordingly in an effort to create the most specific fitness programme for rugby players. These specific fitness programmes may contribute to a higher fitness level of players, which is required to cope with the modern day type of rugby (King *et al.*, 2010).

2.3 WORK INTENSITIES OF RUGBY:

Rugby union is a game played for two 40-minute halves periods with a 10-minute rest between the two periods and injury stoppages during the game, which can be described as a high-work rate, multi-activity sport. Rugby is classified as an intermittent, interval type of sport with short bouts of high-intensity activities (e.g. running and passing, sprinting, tackling) and longer periods of lower-intensity activities such as standing, walking and jogging (Nicholas 1997; Duthie *et al.*, 2003; Gamble, 2004a; Gabbett, 2005a; Roberts *et al.*, 2008). The work rate of players can be related to overall match performance, as a high physical involvement in a rugby match increases total work performed by a player. Performance indicators can be obtained from the statistics of a match (Bracewell 2003). Mclean (1992) found that the mean duration of work in a rugby union game was 19 seconds; he further indicated that 60% of the duration of work periods are between 11 and 25 seconds and 5% are between 50 - 60 seconds. The most work-to-rest ratios in this study were between 1:1 and 1:1.9.

McClean (1992) further indicated that an analysis of international rugby in 1990 showed that work-to-rest ratios are on average 80:106 per game, 20% are 2:1, 18% are 1:4 and higher and 5% are higher than 3:1. Deutch *et al.* (1998) found average mean work-to-rest ratios for U/19 elite players to be 1:1.4 in forwards and 1:2.7 in backs. More specifically, the mean work-to-rest ratios were as follows: back-row forwards 1:1.2, props and locks 1:1.8, inside-backs 1: 3.6 and outside-backs 1:2.2. During a game the high-intensity efforts of players are often followed by periods of incomplete recovery for the players. This emphasises the intermittent nature of the sport's physical work required in a match. Nicholas (1997) specifically indicates that these high-intensity activities typically range between 5 to 15 seconds, with the incomplete recovery below 40 seconds. According to Deutch *et al.* (1998), total average distances covered by U/19 elite players in a rugby match according to is 5,530 - 5,750m by backline players, of which 2,110 - 2,600m were jogged and 208 - 297m were sprinted. The forwards, however, covered a distance of 4,080 - 4,400m of which 2,940 - 3,050m was jogged and 94m sprinted. Table 2.1 represents more detailed results of the above-mentioned study on distance covered during a match the different activities in a match.

Table 2.1: Mean distances covered by the four positional groups (Adapted from Deutch *et al.*, 1998)

Total distance (m)				
Activity	Props and Locks	Back row	Inside backs	Outside backs
Maximum distance (m)				
Walking	55.5	68.7	77.6	63.5
Jogging	65.3	62.9	56.5	63.8
Cruising	27.2	23.4	28.3	25.3
Sprinting	29.0	17	24.2	27.1
Average distance (m)				
Walking	14	13.1	13.6	22.4
Jogging	21.8	19.4	16.3	20.6
Cruising	13.5	11.2	12.9	11.3
Sprinting	19.8	14.5	18.8	23.6

Takarada (2003) indicated from a study that was done on Japanese amateur rugby union players that the mean duration of the work and rest periods of the players during a match averaged between 21.5 and 24.3 seconds respectively. It was also indicated that high-intensity intermittent activity had taken place more than a 100 times per match. Duthie *et al.* (2003) found that forwards' average sprinting times were 0.7 seconds slower than backs', while backs spent 52 seconds more on sprinting in a game. According to Duthie *et al.* (2006b), the average rest periods in rugby games are often influenced by long breaks such as penalty goals, conversion attempts and the stoppages for injuries. He further indicates that rest periods range on average from 0-20 seconds for all players, with an exception for outside backs, who have rest periods beyond 100 seconds.

A study by Eaton and George (2006a) indicated that there was no significant difference in quantities for work-to-rest ratios, although they found a significant difference in time work-to-rest ratio. Forwards had a 1:8.3sec mean time ratio and backs a 1:13sec. The particular ratios were: props 1:10.13, hooker 1:8.28, locks 1:7.55, loose forwards 1:7.48, scrum halves 1:10.38, inside backs 1:12.45 and outside backs 1:14.63. The researchers further indicated that loose forwards spend the shortest amount of time performing low-intensity activities during a match, while outside backs spend the most time doing low-intensity activities. Forwards spend an average of 10.2 minutes in high-intensity activities and back an average of 6.62 minutes.

Deutch *et al.* (2007) analysed rugby players in six professional rugby matches, indicating the time spent on different types of match activities. The study indicated that players engage, percentage wise, in high-intensity activities during the whole match time: 12-13% for forwards (of which 80-90% high-intensity activities were scrumming, rucking and mauling) and 4.5% for the backline players (of which 60-70% were in the form of cruising and sprinting). In the same study the total work done by front-row forwards was 13.6 min, 11.6 min. for back forwards, 5.1 min for inside backs and 4.7 min. for outside backs. 40% of the average work-to-rest ratio of rugby players in the study is less than 1:7 in general.

The average work bouts of forwards are typically 20-25 seconds long, while backs' work bouts are 12-14 seconds in duration. Both front-row and back-row forwards have done over three times more high-intensity efforts per match than the backs. Forwards tend to spend more time in physical contact and static exertion activities like scrumming, rucking and mauling than the backs, who spend two to three times more in high-intensity free running Deutch *et al.* (2007). They also verify these findings, as indicated in the study, that forwards spend a total of 7:31min more engaged in work than backs, which on the other hand have a total of 5:36 min more rest than the forwards. Interesting to note in the study was also that back rows made 13 more tackles than backline players. A research study by Quarrie and Hopkins (2007) on the Bledisloe Cup series, which researched the changes in elite rugby match activities, noted that the total tackles made in a game showed an increase as in 1995 the average total of tackles made was 160 to the 270 in the 2004 Bledisloe Cup.

Roberts *et al.* (2008) found in his research on elite English rugby union players that backs covered a total average distance of 6,127m, of which an average of 2,010m was jogged and a total of 207m sprinted. The forwards travelled on average a total distance of 5,581m, of which 2,024m was jogged and 164m was sprinted. The researchers also indicated in the study that forwards perform longer periods of high-intensity activities than backs, as they spend an average of 9:09 minutes in such activities, against the 3:04 minutes average of backline players. Cunniffe *et al.* (2009) used a global positioning tracking system to evaluate the physiological demands of elite rugby players during a team selection game, with results indicating that an average distance of 6.9km were covered during the game. 5% was spent doing high-intensity running and 87 moderate-intensity runs were made.

2.4 ENERGY SYSTEMS USED IN RUGBY:

Exercise intensity determines which primary energy system is used during exercise or rest. However, the complete supply of energy is not given by a single energy system, but rather a combination of it (Baechle & Earle 2000).

Gastin (2001) also states that a mixture of the energy systems is used to provide energy during different types of activities and summarises the systems as follows: the anaerobic energy system is divided into the alactic and lactic system, which can provide a short, but limited rapid energy supply to the muscles during an activity, while the aerobic system can also provide a more sustained energy release when engaging in lower-intensity types of activities. Table 2.2 summarises energy contribution of the aerobic and anaerobic systems during maximal exercise.

Table 2.2: Estimates of anaerobic and aerobic energy contribution during selected periods of maximal exercise (Adapted from Gastin, 2001).

Duration of exhaustive exercise (sec)	% Anaerobic	% Aerobic
0-10	94	6
0-15	88	12
0-20	82	18
0-30	73	27
0-45	63	37
0-60	55	45
0-75	49	51
0-90	44	56
0-120	37	63
0-180	27	73

In the sport of rugby it is generally accepted that players must rely on the aerobic system, as motion analysis studies indicate that 85% of the game is spent in low-intensity activities (Morton, 1978; Deutch *et al.*, 1998). Data from similar time motion analysis studies also shows that rugby union players engage in many short high-intensity activities such as running, tackling, pushing and competing for the ball in rucks and mauls, etc., with short incomplete recoveries (Docherty *et al.*, 1988; Deutch *et al.*, 1998). The intermittent nature of rugby union implies that the oxidative (aerobic) and creatine phosphate (anaerobic) pathways are the major contributors to adenosine triphosphate (ATP) regeneration during rugby games (Deutch *et al.*, 1998).

Duthie *et al.* (2003) indicate in their review article that 95% of activities on the rugby field last less than 30s, with the rest periods in general greater than the prior work activity engaged in by the players. These intense-effort activities undertaken by rugby players' place considerable stress on anaerobic energy sources, while the aerobic system provides energy during repeated efforts and help in recovery during the game (O'Conner, 2004; Gabbett, 2005a). Kamenju *et al.* (2006) also indicate that the 80-minute duration of a game requires rugby players to have a good aerobic fitness base, to help sustain a large cardiac output for a player to repeatedly engage in the start and stop activities of the game.

A study by Deutch *et al.* (2007) indicated that forwards only get around 35 seconds of recovery before the next high-intensity activity is done. Backline players get plenty of recovery time between high-intensity efforts, estimated at 88 to 115 seconds. Other results in their study indicated significant demands on all energy systems in all playing positions, with a greater reliance on anaerobic glycolytic metabolism in forwards, specifically the lactic system, as they are regularly involved in intense non-running activities like rucking, mauling, scrummaging and tackling. As backs have more recovery time between bouts of play, they are more dependent on the alactic system. Bompa and Claro, (2009) summarise general ergogenesis for rugby union matches to be a 10% contribution of the alactic system, 30% of the lactic Acid system and 60% of the Aerobic system. Table 2.3 specifies the specific contribution of the Alactic and Lactic acid energy system of the different playing positions in rugby.

Table 2.3: Position-specific ergogenesis (Adapted from Bompa & Claro 2009).

Position	Ergo-genesis
Props, Second rows and Fly-Halves	Alactic:60% Lactic:40%
Loose forwards, Hookers and Scrum-halves	Alactic:30% Lactic:70%
Centres, Wings and Fullbacks	Alactic:70% Lactic:30%

2.5 TRAINING PRINCIPLES OF RUGBY:

Conditioning of rugby players is of great importance to coaches, as players who are on top form and physically in the best condition can optimally perform in matches (Takarada, 2003). To achieve optimal conditioning of players, some general training principles are needed to be applied by strength and conditioning coaches. Duthie (2006) indicated that important training principals that should be applied in rugby are specificity, overload, progression and reversibility all in a periodized manner.

2.5.1 Specificity:

Sport-specific training is a training principle that is considered to be one of the important aspects used by fitness coaches, as each section of training should positively contribute to the player's specific functions on the sport field (King *et al.*, 2010). The review study of Coffey and Hawley (2007) indicates that exercise mode has an influence on training adaptations in skeletal muscle. To optimise athletic performance, specific combination training is needed, as aerobic endurance and resistance training could negatively influence each other.

To furthermore apply the principle of specificity to training, the demands of the game must be completely understood in terms of physiological demands experienced by players to provide the correct metabolic conditioning and accurately apply the correct training intensity during practice sessions (Deutch *et al.*, 1998; Eniseler, 2005). Smith (2003) agrees as he states that, for effective training of individuals to take place, specific components of the sport must be addressed and the basic physiological elements such as strength, stamina, speed and skill must be incorporated into the training programme to develop the required sport-specific characteristics.

Specificity of training has been documented as one of the best modes of training for athletes and is also an applied method in rugby conditioning (Gamble, 2004a). Skill-based conditioning is a method applied to elicit specific game situations and circumstances to favourably condition the players according to the metabolic demands of the game, making the player game fit and ready (Gamble, 2004a).

Coaches should ensure that players develop general fitness during pre-season and steadily progress to more specific training for the in-season (Kamenju *et al.*, 2006). According to Duthie (2006), game movement pattern analysis and individual physical fitness profiles can help strength and conditioning coaches to develop a highly effective specific training or conditioning programme. Game analysis can establish specific work-to-rest ratios, as well as time spent in high- and low-intensity activities that can be trained. Individual fitness profiles can furthermore assist coaches to recognise weaknesses in the player and specifically improve it, or fine-tune some fitness aspects and skills.

The physical tests used to evaluate progress of the individual should also be specific tests. Field tests can contribute to specificity of testing, as it can closely replicate the training undertaken by athletes, as well as game demands. This may give a true indication if the conditioning programme followed by the athletes is working and if the athlete meets the requirements to sustain the demands that would be experienced by the athlete in his sport (Gamble, 2006).

According to Duthie (2006), to correctly condition players to the specific demands encountered by them during a game, training should focus on repeated brief high-intensity efforts with short rest intervals. There is also different energy demands of rugby placed on players. This is better known as positional differences. Specific conditioning for players who play different positions can also be incorporated into training regimes to achieve specificity in training sessions to optimally prepare players (Doutreloux *et al.*, 2002; Eaton & George, 2006b).

Training must therefore be refined even more. A good example of applying the principle of specificity would be that conditioning for the forwards should put emphasis on the higher work rates of the game, including activities such as wrestling for the ball, etc., while extended rest periods can be provided during speed training for the backs as they experience it in a game situation (Duthie, 2006). The importance of fitness training for rugby players should therefore definitely try to reflect their position's specific demands

as closely as possible. This can be well achieved by specifically applying the transfer of training effect, using training of the aerobic (oxidative capacity) and anaerobic type of exercises respectively (Gamble, 2006). Game-specific training programme may also enhance a better transfer of physical fitness to the rugby player's actual performance on the field if the specific training includes physical conditioning and skills training (Gabbett *et al.*, 2007). However, a recent study by Gabbett *et al.* (2009b) indicated that game-specific training may not always achieve the specific high-intensity demands of the repeated sprints done by individuals during a game, but can still be used to effectively condition players to increase their physical fitness.

Sirotic *et al.* (2009) further also indicates that repeated sprint training must be done with game-specific skills such as physical collisions included in the sprints, as repeated sprint activities in matches occur mostly when a team defends, as the player must repeatedly tackle the opponent or be on attack when the players are support runners for the ball carrier. Coaches can therefore closely mimic match intensities by creating game-specific situations in the normal training environment to maximise team performance.

2.5.1.1 Position-specific conditioning:

As mentioned earlier, the principle of specificity can further be applied by conditioning an athlete according to the position they play in a team. Through the development of a player profile in terms of the physical capability of a player, psychological state, technical and tactical skills of a player, the above-mentioned process of specific conditioning could be made easier as specific needs of players can be identified (Bompa and Claro, 2009). Firstly a clear understanding of the different positions in a rugby union team is needed. Duthie *et al.* (2003) and Bompa and Claro (2009) describe that a rugby union team has 15 players on the field at once; seven forwards and eight backline players. There are also seven reserve players, to be used as substitutes for the starting 15 players in case of injury or to be used as an impact player (Meir, 2007). The seven forward players can further be sub-divided into three groups, namely the front row, consisting of two props, a tight-and loose-head prop (nr1 and 3) and a hooker (nr 2). These positions are mainly determined by their specific roles in the scrum. The second

group is the second row players consisting out of two locks (nr 4 and 5) and the last group of the forwards are the loose forwards, two flanks (nr 6 and 7) and an eight man (nr 8). Backline players can also be divided into three groups, two half backs, a scrum half (nr 9) and fly half (nr 10), two inside backs called an inside centre (nr 12) and outside centre (nr 13) and lastly three outside backs, a left wing (nr 11), right wing (nr 14) and a fullback (nr 15).

Some general match performance indicators for a whole team according to James *et al.* (2005) are:

- Ratio of successful versus unsuccessful tackles made;
- Successful versus unsuccessful carries of the ball; together with
- Number of metres gained when carrying the ball;
- Completed passes between players;
- Handling errors;
- Penalties conceded;
- Turnovers won; and
- Tries scored

Each of the position groups furthermore has different roles during a rugby match. Specifically conditioning the players according to the position that is played, a whole team's performance can be optimally increased by these individualised conditioning training programmes. Performance indicators can be used in a process of creating player- specific position profiles and can further measure players' overall form in matches (Bracewell, 2003). Bangsbo *et al.* (2006) suggests that the tactics that are implemented by coaches in the sport of soccer also influence the physiological demands on players during a match and training should be adjusted according to these tactics. In rugby union, different game tactics would also have an influence on the type of game players in different positions will have to play to execute the tactical play, making physiological requirements different for each playing position.

A study by Quarrie *et al.* (1996) specifically analysed the differences between forward and back-line club-rugby players. The researchers indicated that specific performance requirements are needed by rugby players to cope with the different demands required for each playing position. The study further mentioned that props were the least aerobically fit; therefore conditioning coaches should make sure that props are aerobically match fit. The study by Wheeler and Sayers (2009) did a notational analysis on seven Super 14 rugby matches to determine the effect of contact skills on predicting tackle breaks. It was indicated that outside backs broke through the most tackles percentage wise, followed by loose forwards, while inside backs carried the ball more than the outside backs. Such studies can provide some valuable information for creating player profiles and individual training can therefore take place.

Nicholas (1997) also indicates the need for individualised training programme for rugby union players, as anthropometrical and physiological characteristics differ among individuals. Doutreloux *et al.* (2002) also conclude that each playing position requires different conditioning programmes to optimally develop each player on a rugby team. Duthie *et al.* (2003) also indicated in a review article that the physiological demands between positions played differ and therefore position-specific conditioning is needed. The researchers further concluded that back-line players are in general more aerobically fit, while forwards tend to have a greater aerobic endurance.

Mashiko *et al.* (2004a) studied the effects of exercise on the physical condition of rugby players by measuring changes in anthropometrical composition and blood chemistry markers during a training camp. The researchers noted that the development of position-specific exercise structures is needed as differences between blood chemistry profiles between forwards and backs were found. Backs tend to run more during practice sessions; therefore they can dehydrate faster than forwards. While forwards, who participate more in physical contact activities during practice sessions, are more likely to suffer from muscle damage, they may need extra recovery time between and in sessions. The study of James *et al.* (2005), which develop position-specific performance

indicators for rugby union players, confirms that a significant difference exists for all playing positions on a rugby field.

Another benefit of the implementation of an individualised conditioning programme is the fact that it can form part of an effective injury management programme for rugby players (Brooks *et al.* 2005) and will be discussed later on in the review. Van Gent and Spamer (2005) investigated positional group differences and found the following in U/19 elite rugby players' sprinting tests results: a significant difference in sprinting endurance between tight- and loose forwards was established. The average 30m sprinting time of the players was 4.87 seconds for the tight forwards, 4.47 seconds for loose forwards and 4.14 seconds for back-line players.

Eaton and George (2006b) suggest that performing repeated runs of 10 metres is recommend for lock forwards, as they tend to spend most of their running in a game over an average distance of 8 metres, mostly in a straight line. For outside backs, more sprints over a distance of 25 metres are proposed and according to the work-to-rest ratio of players, locks should get less recovery time between sprinting exercises. Players should therefore be grouped according to the position they play when doing sprinting activities or fitness drills during training. In the tackle situation, loose forwards execute the most tackles in a match, with an average of 13 tackles, which is mostly around the rucks, while outside backs make an average of 6 tackles per match. To mimic these tackling demands it is suggested that, when performing fitness contact drills, distance travelled to tackle a tackle bag can be varied for the different positional groups (Eaton & George, 2006b).

Agility drills can be performed by players, together with skills needed for the specific position, with a variety of high- and low activities according to match situations. Scrumhalves for example, perform a star agility drill with passing and tackling drills, with 19 seconds low intensity activities after a high-intensity drill was done (Eaton & George, 2006b). The study by Deutch *et al.* (2007) also indicates that, due to the high-intensity running nature of the backline players in a match, especially outside backs, who do the

most sprinting work during a match, sprint more than their front row forwards in a match, which emphasises the importance of sprint training for the players especially the back-line.

Trewartha *et al.* (2008) analysed the kinematics of lineout throwing (which is usually performed by the hooker in a team). The study indicated by the study the importance of core strength and lower-limb strength for hookers as it can influence throwing accuracy and performance in the lineout. Jarvis *et al.* (2009) suggests that forwards' conditioning programme should focus on improving facets that are related to their higher-intensity activities in a match, while backline players; focus on conditioning must be more on improving speed and agility, using different running tests as a means of training.

Holway and Garavaglia (2009) did a kinanthropometric profile on 7 rugby teams participating in the Buenos Aires Rugby Union competition. The study indicated that centres were very mesomorphic compared to other back-line players as they need a strong muscle structure for tackling and breaking tackles. Scrumhalves should have good agility, while wings require good sprinting speed and were the leanest of all rugby players. The study recommends that kinanthropometric profiling can be included to gain information on position-specific requirements. The study by Dellal *et al.* (2010) suggests that a physical analysis, together with a technical and tactical overview of matches, can provide coaches and conditioning staff with valuable information on position-specific requirements. The researchers concluded that training could be altered according to the results obtained from above-mentioned evaluations.

2.5.1.2 Position-specific rehabilitation of injuries:

It is an well established fact that rugby players with injuries must fully rehabilitate and recover from their injury before returning to normal training and participation in matches, as it is a large risk factor that these players could be injured again (Lee *et al.*, 2001; Quarrie *et al.*, 2001; Gabbett & Domrow, 2005). Quarrie *et al.* (2001) researched risk factors for injuries in rugby over a whole competitive season. The position a player plays was determined not to be a risk factor for injury, as no significant differences were

determined between injury profiles for the different positions. However, the study established that midfield backs sustained the most severe injuries compared to the forward group and was also the group of players who was mostly kept out of the season due to injuries. In addition, players with the highest body mass index were likely to have a higher injury rate than those with a lower body mass index. Injury risk profiles could be useful in rehabilitation of injuries. Specific intervention training programmes can also be therefore an effective means of minimising injury. A research study on Australian football players by Verrall *et al.* (2005) concluded that specific pre-season conditioning programme that included match-specific interval running, drills and stretching of the lower limbs while fatigued in practice sessions, decreased the total number of hamstring injuries in players over a season.

Eaton and George (2006b) indicate that position-specific rehabilitation can be implemented in the sporting code of rugby union as an effective means of recovery from an injury. The focus of rehabilitation programme of players should therefore be on incorporating similar physical demand experiences in a rugby match, for example, forwards need power to scrum, therefore field-based rehabilitation for forwards can include pushing movements against an object and progressively let the injured player return to normal scrumming. An informative study by Lark and McCarthy (2009), who measured rugby players' cervical range of motion after a rugby match in terms of flexion, extension, left and right rotation, indicated that the position a player plays has an influence on the neck's range of motion, as forwards had a decrease in neck extension and left lateral flexion, while back-line players had reduced neck flexion ability. The study indicated that the results of the study could be used in a rehabilitation setting and muscular and neuromuscular components must be examined. Kaplan *et al.* (2008) indicated that different playing positions indeed elicit different injury rates. An increase in the number of injuries in the professional era could be explained by the change in the roles of each position as rugby becomes a faster game and the size of players' increases. Involvement in the number of tackles in a game due to the faster game speed also enhances the possibility of an increase in injuries.

A recent research study by Brooks and Kemp (2010) investigated position-specific injury profiles of English professional premier league clubs over a period of four years to indicate whether position specific injury prevention is needed in rugby union players. The study indicated that forwards had a total of 1,307 injuries and backs had 1,177 injuries, with no significant difference between match time lost due to injuries between the two groups. However a significant difference was determined in the injury profiles of the players. The following was found in terms of the injury profiles of the players according to the position they played: Loose-head props and hookers mostly had cervical and shoulder rotary cuff injuries that kept them from playing matches, while tight-head props had injuries of the lumbar spine and lower leg (mostly to the calf region).

Locks had more ankle injuries; the nr six flanks mostly suffered neck injuries (specifically injury to the cervical facet joint) and nr seven flanks thigh injuries (specifically the hamstring muscle). Scrumhalves missed matches mostly due to shoulder- and knee injuries, fly halves and wings had mostly thigh injuries (specifically hamstring injuries). Centres had more neck and shoulder injuries than compared to the other backs.

It can be concluded from the above-mentioned studies that applying position-specific rehabilitation strategies is indeed necessary to ensure effective rehabilitation of an injury. Players can therefore successfully return to training after sustaining the injury and minimise future risk in getting the same injury due to the rehabilitation technique.

2.5.2 Overload:

Overload is when an individual works harder in order to challenge the body beyond its current capacity; it can be applied in terms of volume, intensity, perceived effort, frequency and recovery (Baechle & Earle, 2000). The magnitude of the training load must be correctly applied to achieve optimal training benefits. This is achieved by increasing training volume with the sufficient recovery needed in-between for adaptation to take place (Smith, 2003). The total overload placed on an individual during training must be high enough in volume and intensity to achieve the necessary positive

physiological adaptations for increased athletic performance (Polman & Houlahan, 2004).

Gabbett (2004) suggests monitoring training loads by multiplying the intensity of the training sessions with the total duration of practice sessions. Luger and Pook (2004) state that load variables such as exercise selection, intensity, frequency, rest and volume must be altered to fatigue muscular, nervous and energy systems to achieve super compensation. Increasing the training load must be done in a certain order (the order is first an increase in frequency, then volume or duration and lastly an increase in intensity) to gradually build the players fitness without the risk of excessive fatigue and injury (Duthie, 2006).

Meeusen *et al.* (2006a) defines training as a way to disrupt homeostasis of the human body with the goal to acutely fatigue it and subsequently improve performance of the athlete. Gabbett and Domrow (2007) states that, for collision sports such as rugby, training volume must be maintained with a balance between the load needed for improvement and the maximum load tolerable by the players, to keep injuries at a minimum. It is further suggested in the study that to achieve a low rate of injury and maintain performance the early competition-phase training implemented must have a reduced training load.

Kelly & Coutts (2007) agree as the amount of overload placed on players is determined according to the time in the rugby year and factors that influence the training load in-season are the training days between matches, travelling and quality of the opposition. Gabbett (2005c) proved that by applying an effective training programme with the right amount of overload during a rugby league season for two sessions per week, it can result in an increase of aerobic fitness, muscular power and agility in the first part of an Australian rugby league season.

2.5.3 Periodisation:

Baechle and Earle (2000) define periodisation as an organised overall conditioning programme plan, which is divided into cycles or periods to help increase performance and reach long-term training goals without overtraining of the athlete. A good periodized plan is divided into in-season and off-season programme preparation with non-specific strength training and after that, changing to highly-specific technique routines (Zatsiorsky, 1995). Baker (1998) states that a well planned periodisation plan helps to effectively incorporate strength training, tactical and technical training to optimise performance of athletes, where during the in-season the priority shifts to technical and tactical training, while strength and power that was the primary focus during the pre season is maintained. Different type of approaches of periodisation is also used by strength and conditioning coaches. The following studies clearly illustrate the above mention statement.

The study by Buford *et al.* (2007) distinguished between two types of periodisation models, namely the linear model where training volume and intensity are altered over long periods of time, and the non-linear model, where volume and intensity are altered more frequently. The study further indicated that both the above-mentioned models were effective in increasing the participant's upper-body and lower-body strength over a period of nine weeks. These models described are part of the generally known traditional periodisation model, as Issurin (2010) refers to another type of periodisation model, namely the non-traditional model or the block periodisation method.

Issurin (2010) reviewed and described the model in his research article. It incorporates different phases of intensified specific training of fitness aspects in an attempt to optimise performance by manifold peak in performances during the competitive season. The phases consist of three cycles, with each one lasting a different number of weeks. Firstly aerobic- and cardiovascular fitness is developed, the next cycle focuses more on sport-specific aspects needed by an athlete and lastly a cycle where drills that mimic match demands are incorporated, with the goal of fast recovery during a match. It was further concluded by the author that block periodisation is an effective model to be used

for sports that have an extensive competition phase, as it may assist in a structured long term plan for conditioning individuals. Garcia-Pallarés *et al.* (2010) compared the application of a block periodisation model versus the traditional model in well trained kayakers and indicated that similar results were achieved in terms of physiological aspects. However, the total amount of training volume was lower than with the traditional model, making overtraining less likely to occur in individuals following the non-traditional approach of periodisation. The implementation of a periodized training programme can contribute to the development and maintenance of fitness, as well as prevent unnecessary injuries in players (Marshall, 2005).

Marshall (2005) further indicated that the three components that are essential for rugby union players to include in a periodisation programme for physical conditioning are power, strength and mass, as it is needed to make tackles, scrumming for the forwards, competing for the ball in rucks by means of wrestling and removing the opponent from the ball. Aziz *et al.* (2006) did a research study on soccer players during a competitive season of a soccer league. Fitness tests that were done to monitor changes during the whole season included anthropometrical measurements; a 20m multistage shuttle run, 5m and 20m sprint times and a vertical jump test. It was performed during pre-season, in-season, mid-season and end-season session. The researchers suggest high demanding and volume conditioning programmes during the off- and pre-season can result in an increase in aerobic endurance, speed and lower body power.

Silvestre *et al.* (2006) also examined the change in body composition and physical performance parameters of soccer players during a whole soccer season which lasted 16 weeks. It consisted of a total of 21 matches, 62 field practice sessions, 12 weight training sessions, five plyometric and speed sessions, seven stamina sessions and six regeneration sessions. The results of the study indicated that the physical performance variables relatively stayed the same except for total body power, which significantly increased with 17.3%, and lower body power, with a significant increase of 10.7%. As for the body composition of the players, an increase in lean body mass resulted in a significant increase in body mass. The study illustrated that a proper conditioning

programme based on a non-linear periodisation model that was used for intensity and training volume induced in the study together with players who started the in-seasons with an already good base of fitness, can effectively aid in the optimised performance of players during a competitive season.

Brooks *et al.* (2005) researched England's 2003 Rugby World Cup national rugby squad to establish the nature and cause of injuries to the players during the preparation and competition phase of the team. The average number and length of the training sessions were also recorded for a 64 week period. The pre World Cup phase lasted 19 weeks, with an average of six training sessions per week for 85 minutes per session. The middle phase for the duration of ten weeks, which included a rugby training camp and warm-up matches to improve the players' physical condition, consisted of 12 training sessions per week. During the competition phase of eight weeks in the study, six sessions per week were performed by the players. The researcher indicated that, on average, 17 injuries per 1000 hours of participation in rugby activities (matches and training) occurred and concluded that endurance type of running activities during practices and physical contact collisions in matches were the major causes for injuries. More detail about the results of the study in terms of injuries sustained during the different phases of preparation is indicated in Table 2.4.

Table 2.4: Incidence and severity of injuries as a function of playing position, activity, and phase of preparation for the Rugby World Cup (forwards: n = 32; backs: n = 31) (Adapted from Brooks *et al.*, 2005).

Incidence of injuries/1000 h (average severity, days)				
Phase of preparation	Match		Training	
	Forwards	Backs	Forwards	Backs
Pre-World Cup	242(20)	197(18)	5.0(20)	5.0 (7)
Training camp	63(19)	287 (13)	7.2 (14)	9.1(19)
Rugby World Cup	168(9)	312(4)	1.3(4)	9.4 (6)

Gabbett (2005c) describes the off-season as the period before structural and functional training is done. Monitoring of rugby players during this time is difficult, however general strength exercises are recommended.

Duthie (2006) also state that a general periodized plan overall has the goal to progressively increase in training load in the pre-season phase, with the focus on getting players in a good condition, maintaining fitness in-season and modifying training in the off-season to minimise the effect of reversibility in fitness levels, as previous seasons, training can influence the current fitness state of a athlete. He further underlines the importance of evaluation of players to indicate effectiveness of the implemented training programme. According to Kelly and Coutts (2007), periodisation phases include general preparation, specific preparation, pre-competition and competition phase. In rugby, the phases consist of an active rest period, off-season, pre-season and in-season. They also state that it is important that coaches are well educated about the training processes, measuring volume and intensity of skill training sessions, as well as finding the correct balance between training, rest and recovery. Kelly and Coutts (2007) further suggest that, in a periodisation programme, during the active rest phase, corrective exercise and control drills must be done along with cross-training. In the off-season the focus must be on stability, patterns and loaded-strength drills. Also general and specific fuel mix and speed and agility drills must be done in the off-season, as this is the phase where great improvements in rugby conditioning should be made.

Moore and Fry (2007) researched American football players during a 15-week off-season programme, which consisted of three phases. In phase one, which lasted four weeks, weight training was done, in phase two both weight training and conditioning drills were done for 5 weeks. In the last phase, 15 football training sessions were performed. The study further indicates that off-season training should be used to maximise performance when the in-season begins and to maintain it during the in-season. The researchers further suggest that a reduced training load, together with mixed intensities, would aid in maintaining the adaptations from off-season into in-season.

In the pre-season, the training becomes more specific and power-specific fuel mix, speed and agility drills must be done, while stability and pattern strength abilities must be maintained. Lastly, the in-season phase is characterised by blocks of fuel mix, strength, power, speed and agility training drills (Kelly & Coutts, 2007). Bompa and Claro (2009) provide a guideline for planning a periodisation of bio-motor abilities for rugby; it consists of technical training, tactical training, strength and power training, agility training and speed training, as well as endurance training. Their programme is as follows: In the first month of technical training, they focus on individual skill development and later in months two to three these individual skills are integrated with the team tactics. During the in-season these skills are adapted according to the opposing teams. The tactical training is addressed in month's two to three where fundamentals of offence and defence are developed. In-season these tactical skills of offence and defence are refined and flexible team tactics are built according to the opposition. Strength and power are built from month one to three, where maximum strength and power are gained in the preparatory phase during the in-season. Agility training is done in month two of preparatory, where new skills are learned. In month three, agility and quickness is done and maintained in-season. Maximum speed work is done in month two with alactic and lactic tactical drills, as well as short repetitions of maximum speed. Endurance training forms the base of rugby fitness that will facilitate faster recovery-regeneration from game- and training- induced fatigue.

In month one, aerobic training is done and is followed with mixed game and position-specific endurance. In month two and three game and position-specific drills of the lactic and aerobic system are done. It is important to note that game and position-specific endurance continues to be trained throughout the in-season. Clark *et al.* (2008) researched season to season variations in physiological data of elite soccer players by testing the players before a season, during the season and at the end of a season, over a period of three complete soccer seasons. The study pointed out that the maximal oxygen capacity (VO_2 max) of the players remained constant over the three seasons, physiological performances increased during the mid-season, with a decline in anthropometrical and physiological performances at the end of the in-season.

Hanekom *et al.* (2008) monitored U/19, U/21 and senior rugby union players' anthropometric and motor skills over a period of two complete rugby seasons. The importance of incorporating an effective conditioning programme for rugby players over a long period of time was highlighted by the study. It was indicated by the motor skill data, the speed of all three groups significantly increased, while the players' agility also showed improvement. The anthropometric data also showed improvement in body fat percentages. Jarvis *et al.* (2009) outlined a ten week pre-season training programme for sub-elite rugby union players. The program consisted out two to three rugby-specific practice sessions per week, spending three to four weekly on training.

Posthumus's (2009), literature review article that specifically reviews physical conditioning (including strength- and fitness training) during the off-season, pre-season, in-season and recovery phase, has overall similar findings than above-mentioned authors. However, more detail is stated on the aspect of fitness training, which includes the following: in off-season, it is suggested that if a player's goal is to increase muscle mass (hypertrophy), high-intensity interval training should be prescribed rather than the high-volume aerobic training approach. During the pre-season, as noted before, more specific fitness training should be done that consists out of drills that represent metabolic demands of the game, e.g. according to the work-to-rest ratios for the different positions and development of speed and agility. Maintenance of the fitness level achieved by the players during the previous two phases is important during the in-season. It is suggested that training volume and intensity must be altered according to the difficulty level of the opponents played next. Also important during this phase is to monitor and evaluate players constantly to ensure sustained performance.

Vural *et al.* (2009) agree and state that physical and physiological fitness elements of athletes must be tested on a regular basis for determining whether training loads and intensities of specific periodisation phases are effective. The study of Argus *et al.*, (2010) specifically researched the effect of a four week pre-season training programme on professional rugby union players' body composition, strength and power. The results of the study indicated that it is possible to make strength gains with a short, high-volume

pre-season training programme as upper- and lower body strength of the players increased, together with a small decrease in body fat levels of the participants. However, a decrease in power was detected and it was suggested that, to increase power before the competition phase, training volumes should be lower and fatigue must be kept at a minimum for increased power to occur. Each phase of periodisation must therefore be goal orientated and according to the specific areas that the athlete needs to improve.

2.5.4 Recovery:

Recovery is an important element of any athletes' or coach's strategy to successfully achieving optimal results, whether in training or competition. When effective recovery methods are implemented by using active and passive as proactive methods of recovery can lead to efficient work capacity and promote overall wellness of an athlete (Kellmann, 2002).

Extended periods of intermediate running activities, as in the sport of rugby, induced whole-body muscle soreness, especially the hamstring muscles during a period of 24-48 hours after participation in the activity (Thompson *et al.* 1999). Recovery can therefore not be emphasised enough in the sport of rugby, as the nature of the game includes actions of forceful, high-intensity power production activities performed by players which means that the player's body is highly fatigued after matches (Jeffreys, 2005). The study by Takarada (2003) evaluated muscle damage of players after a rugby match by monitoring the activity of creatine kinase and plasma myoglobin concentrations in the blood. It was indicated that tackles induce a high amount of structural damage to the muscle and recovery from it was noted to be an important element for the performance of a rugby team. Duthie (2006) indicates that adaptation to different training approaches vary in time in the process of observing the effects of the training programme. The necessary recovery is needed for improvement of the player's fitness, therefore overtraining can occur when not enough recovery is allowed.

Optimal exercise performance is the goal of any conditioning programme and recovery can help to attribute to it. Rest management must therefore be applied, as Luger and

Pook (2004) suggest. They state that rest management includes intersset rest (rest between fitness drills in a training session), tapering (reduced volume and intensity of training for optimal performance for a game), active rest and applying the principle of periodisation. Post-match recovery is also an important factor to consider when the competition phase of the season begins. After a rugby match players are highly fatigued and an effective recovery strategy plan is necessary for players to recover from the match and be ready for the training schedule ahead before the next game or training session.

Mashiko *et al.* (2004b) indicated that recovery meals, which form part of an effective recovery strategy, must be according to the position played by the players to increase total recovery time of the players, both mentally and physically. After the match, backline players must consume foods that supply instant energy for their mental fatigue which is mainly caused by energy metabolism used in a match. Forwards must ingest a protein meal together with a high carbohydrate source, as their mental fatigue is caused by both energy metabolism and muscle tissue damage. Jeffreys (2005) suggests a post competition recover strategy which is as follows: within the first five minutes, the main goal is to rehydrate and refuel, which includes eating or drinking carbohydrates and protein in a ratio of 4:1, where high-glycemic index carbohydrates is preferred to be ingested. The next goal is the cooling down period of 5-20 minutes, where players must move lightly in the form of a walk or slow jogging, followed by stretching for 8-10 minutes. This cool down part can aid in the removal of metabolic bi-products, restoring energy system through the blood flow to the muscles and help muscle relaxation. A neural recovery stage of 15-20 minutes follows. It includes the use of contrast showers or baths where players alternate between hot water for 1 minute and 30 seconds of cold water, and self massage to end off the specific recovery stage. General recovery strategies used by athletes and coaches are massage therapy and water immersion methods, but there is still a lack of scientific support.

A study by Weerapong *et al.* (2005) describes that massage therapy is generally used in preparation for competitions, between competitions and to aid in the recovery of the

muscles. The researchers further noted that different massage techniques for recovery is debatable, as more scientific research is needed to establish whether massage is effective in aiding in an athletes performance and injury prevention. Eaton and George (2006b) recommend that in the days following a rugby match, light recovery workouts and practice sessions should be incorporated. Training volume and intensities must therefore be lowered to give the players' bodies enough time to recover.

Another study done by Wilcock *et al.* (2006) indicates in a scientific review article that water immersion strategies such as cryotherapy, thermotherapy and contrast bath therapy might hold some positive benefit as a recovery strategy for athletes. However, further research is needed on these recovery methods to determine if it is beneficial enough to incorporate as a recovery intervention. The study by Barnett (2006) on recovery modalities used by athletes between training sessions agrees that the use of contrast temperature water immersion needs more scientific support although it is incorporated by many athletes and coaches as a recovery intervention. The researcher furthermore concludes that more research is needed on recover interventions to optimally enhance performance of athletes. Tessitore *et al.* (2007) researched recovery interventions for soccer players and states that effective recovery strategies can enhance performance and aid in minimising the incidence of muscle damage.

Halson (2008) recommends the monitoring and inclusion of the quality of sleep as part of a recovery method for athletes, as a poor sleep pattern may lead to underperformance and chronic sleep disturbances may be associated with overtraining. Rowsell *et al.* (2009) investigated the method of applying cold-water immersion as a recovery intervention for soccer players during a four-day tournament where one match was played each day. A thermo-neutral, or cold-water immersion recovery strategy was implemented after each match and the effects on physical performance and biochemical markers of muscle damage (creatine kinase and lactate dehydrogenase levels), as well as perception of reduction of fatigue was measured. The results of the study indicated that cold-water immersion strategies do not significantly reduce inflammation in the muscles, but is effective in reducing the perception of muscle soreness in athletes.

Psychological recovery for individuals is also important. Relaxation is therefore needed and relaxation skills to switch off before the player goes to sleep can be incorporated to aid in mental recovery (Barnett 2006). Hartwig *et al.* (2009) supports the important element of psychological recovery. The researchers did a study on adolescent rugby union players by examining their psychological stress-recovery responses during a rugby season. Participants of the study completed stress-recovery response questionnaires, together with training dairies. The study indicated that players who coped better with the stress-recovery condition were those who achieved the highest training volume during the in-season. Training also leads to stressing of the energy systems and nervous system, which also leads to fatigue where recovery is needed for compensation and adaptation to take place in the body. For this super compensation to occur, sufficient time of rest must be allowed between exercise sessions on the same day and between micro-cycle days. This is known as training recovery and if insufficient recovery time is allowed, the individual may be improperly prepared for the next training session (Bishop *et al.*, 2008; Bompa & Claro, 2009).

If super compensation can take place, the rate of recovery is also improved and thus higher training volumes and intensities can be done without the detrimental effects of overtraining (Bishop *et al.*, 2008). Resynthesis of energy stores that provides energy to the body is important, especially glycogen stores as it can take up to 24 hours to fully replenish glycogen stores in the muscles (Baechle & Earle 2000). Bangsbo *et al.* (2006) further indicates that, if players have optimally filled the body's glycogen stores, higher intensity training can take place, as energy is more readily available for high- intensity activities.

Bompa and Claro (2009) further indicate that full restoration of muscle glycogen after intermittent activities is 25 hours and for prolonged non-stop activities, 48 hours. They further indicate that exercise restoration of muscle ATP/PC (Adenotriphosphate phosphor creatine) takes two to five minutes, repayment of alactic oxygen debt three to five minutes and repayment of lactic acid debt 30-60 minutes. Recovery methods generally used by players include massage, heat and cold therapy, contrast baths,

stretch therapy and active recovery strategies like dry aerobic exercises and water-aerobic exercises (Tessitore *et al.*, 2007; Bompa & Claro, 2009).

Lark and McCarthy (2009) underline the importance of a warm-down period after a match, where stretching (especially the neck muscles) and cooling strategies are needed for recovery purposes. Interesting to note is that in the study of Venter *et al.* (2010), which focused on recovery modalities used by South African team sports, it was indicated that South African rugby players, both on national and club level, spent an average of nine to ten hours training per week, which was significantly more than the other team sport players that participated in the study. This further underlines the importance of recovery for rugby players as training volume is high and rugby players in the study used active cool-down more after training than after rugby matches. Cryotherapy was mostly used by national level rugby players, compared to club players and other sporting codes of hockey, netball and soccer.

In conclusion, recovery in rugby may be implemented as a method to reduce performance impairments on psychological and physiological level, contributing to a healthier, physically conditioned rugby player on and off the field, ultimately leading to an increase in match performance.

2.5.5 Overtraining and injuries

Overtraining is a problematic phenomenon in sport and is a condition that the modern day conditioning coach is faced with (Baumert *et al.*, 2006; Lemyre *et al.*, 2007). It also has a disruptive effect on an athlete's performance if the necessary attention is not given to it (Kellmann, 2002). Budgett (1998) in Lemyre *et al.* (2007) defines overtraining as "A non-deliberate long-term decrement in performance capacity resulting from a failure to recover adequately from an accumulation of training and non-training stress".

Monitoring of athletes' physical and physiological state is an important aspect in conditioning programme and even excessive short-term fatigue can result in long-term overtraining (Smith, 2003). It is further indicated by Smith (2003) that different training

errors can also induce overtraining in athletes, for example a too high or fast total training volume applied at either maximal or sub-maximal intensities may cause overtraining, as well as incorrectly applied micro and macro training cycles. The study by Kraemer *et al.* (2004) also states that if training programmes are not properly planned and monitored in terms of the players' overall physiological state, acute overtraining could occur in athletes which could lead to underperformance. Halson and Jeukendrup (2004) indicate that overreaching is a state that is reached by athletes when an intensified period of training is followed without the necessary rest to recover, which leads to a lack of improvement on the fitness state of the athlete and a short-term state of under-performance can be expected.

Polman and Houlahan (2004) note that underperformance linked with overtraining, and is caused by the interaction between multiple factors, which include training stressors and non-training stressors, such as components of fatigue, exercise load, immune system and nutrition of athletes. If each component that has an influence on athletic performance is not managed properly, a state of overtraining can occur, reducing performance and leading to acute injuries. Psychological factors, which include competition stress, stagnation in training and personal problems, also have an indirect contribution to overtraining (Meeusen *et al.*, 2007). The state of overtraining will ultimately lead to an overtraining syndrome in an individual (Uusitalo, 2006).

King *et al.* (2010) agree and state that when insufficient recovery time is allowed, it results in an ineffective adaptation of the training stimuli that are applied to the athletes and overtraining is likely to occur in the athletes. The researcher further states that by achieving the correct balance between training and recovery, overtraining can be prevented and benefits are likely to occur. The study of Meeusen *et al.* (2006a) indicates that functional overreaching must be the goal of coaches. The process involves a short period of an intensified training load protocol, incorporated with a recovery stage, which will ultimately lead to increased performance. It was further recommended by the study that the intensity of training must be individualised. Altering of training volume must be

done when performance drastically decreases and to treat the overtraining syndrome, sufficient rest must be incorporated by the coaching staff.

Nederhof *et al.* (2006) describes non-functional overreaching as the inability of an athlete to improve in performance after the allocated recovery period of intensified training. The monitoring of athletes can be done by assessing a combination of variables to detect signs of overtraining (Meeusen *et al.*, 2007). Multiple indicators of overtraining may furthermore be used to assist coaches in detecting symptoms of overtraining. The warning signs of overtraining may include disruptive sleeping patterns, general fatigue, inability of the athlete to complete training sessions due to a lack of leg power and a psychological depressed state (Meeusen *et al.* 2006b; Main & Grove, 2009).

Baumert *et al.* (2006) are of the opinion that heart rate variability and baroreflex sensitivity variability can also be used as an indicator of states of overreaching, as both these variables were significantly reduced during an increased intensity training programme over two weeks. Recovery time needed by an individual to return to a normal physiological state from functional, non-functional and the overtraining syndrome differ from each other, as the most undesirable state of the overtraining syndrome can take months to years to recover from, while even non-functional overtraining could see an athlete on the sideline for several weeks to months (Nederhof *et al.*, 2006).

Phillips *et al.* (1998) indicated that an increased rate for injuries was detected per 1000 hours of participation in rugby league training and matches over a period of four rugby seasons. The study also noted an increase in percentage of injuries sustained during training sessions for the last two seasons of the study and suggested that insufficient recovery time that was not allowed for the players between seasons most likely contributed to an increase in the number of injuries. Lee *et al.* (2001), who researched the influence of pre-season training on rugby injuries, is of the opinion that a players' overall fitness state (which includes the overtraining element) is not as big risk for injury than the type of activities that are done by players in preparation training for matches.

The study further showed that players, who completed more pre-season training, were more likely to get injured. However no reasons could be found for the specific result.

A study by Coutts *et al.* (2007) on semi-professional rugby league players compared a normal training programme versus an increased intensity programme (with the intention to over train the players). He found a decreased performance in the multistage fitness test performance, together with a reduced maximal oxygen uptake if the intensity of the training programme was increased beyond normal training intensity. According to Gabbett (2004), differences in the skill and fitness of players can influence the type and severity of injuries. A different conditioning programme are therefore necessary, which vary in load, intensity and frequency, to be implemented according to the level on which the players play their rugby in an attempt to minimise the effect of overtraining.

Gabbett and Domrow (2005), who investigated the risk factors for injuries of sub-elite rugby league players, found that players who have a slow 10 and 40 m sprint time and did not perform well on the multistage fitness test had an increased risk of sustaining an injury. The researchers further indicated that speed and endurance training over a long period of time (25 weeks and more) is fundamental in an attempt to reduce injuries that are caused by fatigue. Gabbett (2004) further mentions that the different phases of a rugby season are also related to the number of injuries. As the season progresses, more injuries occur in amateur rugby league players' matches.

However in semi-professional rugby league players, most injuries occur during early season as high-intensity training loads, are associated with increased injury rates (Gabbett, 2004). The study of Banfi *et al.* (2006) emphasised the importance of the evaluation of players throughout a rugby season, even by measuring haematological parameters, which can be used as an indication of the total work load strain on players. The information obtained from these results can assist coaches in adapting work loads and intensities to optimise the performance of the team without overtraining the players. Bishop *et al.* (2006) noted in a discussion article that a great percentage of injuries at an Australian rugby league club were due to a high-volume running training programme

undertaken by the players. A lower, more match-specific training approach reduced the injury rate caused by training sessions. Overtraining is also associated with psychological “burnout”, which can negatively influence players’ mental state of wellbeing and therefore reduce team performance (Cresswell & Eklund, 2006).

Cresswell and Eklund (2006) indicated that some professional New Zealand rugby players who had burnout syndrome had been over trained, as these players indicated that frequent and high training volumes, together with tiredness, soreness and insufficient recovery time between matches and training led to the players physical and mental fatigue status. The physical nature of the sport of rugby induced regular injuries to the players’ and many factors contribute to these injuries. Optimal conditioning is therefore necessary to minimise overtraining in an overall attempt to reduce injury rates and produce effective rehabilitation of injuries (Viljoen *et al.*, 2009).

According to Viljoen *et al.* (2009), it is debatable if lowering training volume pre-season or in-season can significantly reduce injury rates, as one of the conclusions they came to was that lowering only in-season training can result in a small reduction in acute injuries in a season. However, the overall performance of the team might be influenced negatively and therefore a balance needs to be established between training load, performance and injury rates.

Gabbett (2009b) reports that risks of injuries that occur during training is related to the type of training that is done as traditional training is more likely to lead to injuries than game-based training. Cormack *et al.* (2008) suggest that neuromuscular fatigue, which can be related to overtraining, is induced by the total load of training as well as competition and is best monitored through the measurement of hormonal responses of Cortisol levels to give an indication whether the athlete is in a catabolic state or not. Training loads can be decreased accordingly and more recovery can be incorporated into training schedules until cortisol levels return to baseline level and overtraining can be managed and be prevented.

Gustafsson *et al.* (2008) created a guideline multiple-approach model for monitoring training and recovery in athletes. The model suggests an evaluation after every training session with a Form scale, while weekly monitoring takes place via a mood state test for psychological monitoring and ten-step bounding test, where the athlete completes a series of jump to evaluate lower limb muscular power. Sport-specific evaluation testing is also recommended monthly, as a drastic decline in performance in these tests can indicate a state of overtraining in the monitoring system.

2.5.6 Fatigue

Fatigue can reduce the performance of a team in a match, as the players can not keep up with the intensity and speed of a match in participating in an intermittent type of sport. A reduction in sport-specific skills can also take place under a fatigued condition, which can ultimately lead to an unfavorable match outcome for a team (Reilly 1997b; Lyons *et al.*, 2006).

Reilly (1997b) further states that fatigue is likely to occur during the last part of a match, as many studies indicate a decrease in distance covered by soccer players, and that well trained aerobically fit athletes can minimise the negative effects that fatigue has on performance. The causes of muscular fatigue can be due to a variety of factors such as availability of Adenosine Triphosphate (ATP) for muscle contraction processes and inhibition of some minerals (Natrium and Calcium) needed for muscle contractions (also known as peripheral fatigue factor), as well as a decreased motor unit recruitment (also known as central fatigue factor) (Garrandes *et al.*, 2005; Glaister, 2005). A combination of central and peripheral factors, as described above (central governor model of fatigue) has also been identified as the main contributor to the condition of fatigue (Laurent & Green, 2009).

Tinazci and Acikada (2009) indicate that fatigue is further influenced by the recovery periods between repeated intensified phases of activities during intermittent type of sports. A way to measure fatigue levels is by the measurement of power output of an individual. Research by Mohr *et al.* (2003) on the subject of fatigue in soccer players

reported that fatigue mostly occurs after the completion of a series of high-intensity activities in a match. The recommendation that was made for training programme was that, to minimise the effect of fatigue, players need to improve their capacity to complete numerous high-intensity sprinting efforts, with minimal recovery time between the intensified activities.

The effect of fatigue on muscle strength has received some attention from researchers and the study by Rahnema *et al.* (2003) on a group of soccer players indicated that muscle fatigue leads to a decrease in intensity of running, changing speed and kicking activities in players, which is needed to perform in a match at high intensities. The researchers further pointed out that fatigue caused a reduction in muscular strength specifically of the knee flexor and extensor muscles. The specific reason for fatigue in the study could furthermore not be established. However reduced water content and muscle glycogen levels were noted to cause fatigue in this particular study.

Apriantono *et al.* (2006) specifically researched the effect of fatigue on the leg muscles of football players. The results indicated that force production of the legs does indeed decrease during a kicking action and a decline in general kicking performance can be anticipated. Implication for the rugby player with reference to fatigue of the lower leg muscles and kicking would be specifically applicable to the kickers of a team, especially the goal kicker, where accuracy is of most importance when kicking to the goal posts throughout a match. Strong leg strength and endurance is therefore required by kickers. This can be achieved by doing sport-specific exercises which include leg-strengthening exercises, jumping movements, drills and kicking practice, as these exercises positively contribute to kick performance of kickers (Manolopoulos *et al.*, 2006).

Thorlund *et al.* (2008) also investigated the effect of fatigue on the muscle mechanical properties and neuromuscular activity of handball players after a handball match. The study's findings illustrated that fatigue induced a decrease in the isometric strength of the lower leg muscles (quadriceps and hamstrings) and neuromuscular activity was also negatively influenced, meaning performance of players can drop during a match.

Mohr *et al.* (2005) did a review study on fatigue in soccer and indicated that fatigue mostly occurs during three parts of a soccer match, namely after players completed a short high-intensity run, at the start of the second half and, as mentioned before, at the end part of a game. What is important is that the researchers further note that fatigue can occur during different stages of a match and the causes for the fatigue can vary. It is therefore important for coaches to gain information on the physiological causes of fatigue and address it accordingly in an effort to reduce fatigue. Training programme should incorporate high-intensity exercises in an attempt to fatigue players and then let the players perform tactical and technical drills to improve on these skills under fatigue conditions and to handle fatigue conditions during a match (Lyons *et al.*, 2006).

A study by Gabbett (2008) researched the effect of fatigue on the ability of rugby league players to tackle by means of a tackling session after fatiguing the players. The results of the study illustrated that fatigue does have a negative influence on the tackling ability of players. Training programme should incorporate drills where the tackle techniques of players are improved under conditions where the players are fatigued and also non-fatigued. Thomson *et al.* (2009) researched the effect of fatigue on cognitive skills of ball-sport-playing athletes. The study found those athletes' decision making time and skill decreased as fatigue set in. It was further suggested that if the pattern of cognitive reactions of an athlete could be established, training loads could be adjusted accordingly.

Fatigue is also endured differently by individuals, as some athletes can tolerate a higher level of physiological stress and the technical execution of skills under a fatigued condition also varies among individuals (Stone & Oliver 2009). Coaches should therefore establish the individual's capacity to tolerate fatigue and individual conditioning programs should address this by increasing the individual's tolerance. It was further noted in the study of Bradley *et al.* (2009) that recovery time between passages of play was 28% slower in the last 15 minutes of a match as fatigued set in.

Fatigue further influences the neuromuscular activity of athletes as a match progresses. The research of Zemková and Hamar (2009) on fatigue in soccer players, which specifically focused on the influence it has on neuromuscular activity during rest time after the first half of a match and also at the end of the match, indicated which variables can be influenced. Variables that were tested in the study included leg power, soccer kick ability, agility and balance. The study noted that dynamic balance and long-distance agility performance of players were reduced after the first half, while no significant decrease was detected for the other variables tested. It illustrates the need to practice all activities and agility drills under fatigue-induced situations to optimally enhance performance in intermittent type of sports.

2.6 TRAINING OF THE ALACTIC AND LACTIC ACID SYSTEM:

In intermittent type of sports, quick recovery between activities is needed, as the recovery ability of an athlete could determine the quality and level of performance of the player in a match (Alizadeh *et al.*, 2010). The alactic and lactic acid energy system is therefore an important aspect to specifically train in intermittent type of sports such as rugby.

Spencer *et al.* (2005) reported that repeated sprint exercises that vary in duration, repetitions, work-to-rest ratio and exercise intensity can elevate muscle lactate concentrations to high levels. The study also indicates that when repeated sprint ability of athletes is tested, the test variables should represent the mode of exercise as closely as possible, as well as the movement patterns of the sport.

The study by Little and Williams (2007) specifically recommends a repeated sprint training exercise for intermittent types of training, which consists of 40 x 15 metres together with a work-to-rest ratio of 1:6 for development of the phosphagen energy system, while a rest to work ratio of 1:4 for the same repeated sprint exercise will provide the athlete with the best physiological responses, while fatiguing them the most. Bompa and Claro (2009) recommend that, for training of the alactic system maximal speed-power activities such as sprints, agility drills and plyometrics, must be done at an

intensity of 95% of maximum effort. Players must thus achieve heart-rates between 150-170 beats per minute. The activities last between 10-12 s with rest intervals of three to five minutes and only eight to ten repetitions must be done to ensure that only the alactic system is stressed. The frequency of training is therefore also important and should be two to three times a week during pre-season and once or twice for maintaining it in the rugby season. They further recommend, specifically for training the lactic acid system, exercise bouts may consist of suicide drills, circuits and shuttle runs. All these activities must be between 20-90 seconds long, with players' heart rates below 180 beats per minute and rest intervals of two to three minutes between repetitions. These specific training guidelines can be incorporated by coaches as an aid to specifically improve the players' ability to perform at their lactate threshold for the improvement of the energy system, which is directly linked to the type of exercise that is performed (Durocher et al., 2008).

2.6.1 Speed training:

Speed is a fundamental skill needed to be developed to keep up with the pace of intermittent type of sports. Regular speed training should therefore be incorporated in a conditioning plan for individuals (Whitehead & Cook, 1994).

Speed is associated with sprinting and sprint training may aid in gaining overall speed if both speed endurance and normal sprinting are addressed, for example if improving one's speed over a distance of 50m, the athletes 20m speed will also be increased and will also contribute to sprinting more times at full speed over shorter distances in a match situation, with minimal fatigue (Whitehead & Cook, 1994).

Speed is also an important element in rugby, as a rugby player requires good speed and acceleration for defence and attacking playing periods in a match. Speed training exercises should preferably include the same match running patterns as performed by an athlete in an intermittent type of sport (Pinasco & Carson, 2005). Different methods of speed training are applied by coaches; some include resisted speed training,

supramaximal running and normal sprinting which include an element of speed endurance (Kristensen *et al.*, 2006).

These training protocols should attempt to increase acceleration speed from a standing start and reach maximum acceleration speed as fast as possible to increase sprint efficiency in a match situation (Sheppard & Young, 2006). Lakomy and Haydon (2004) point out that the deceleration phase of sprinting has an impact on sprinting performance in sport matches such as rugby. The researchers indicated that multiple sprints with rapid deceleration actions can induce a faster rate of fatigue on the muscles involved in running. Fitness programme should therefore include deceleration actions for players to get used to the strain it applied to the lower extremities.

In the sport of rugby, the forwards generally require mostly speed to accelerate away from line-out, scrums, rucks and mauls, while backline players need it to accelerate through tackles, thus out-manoeuvre their opponents, and general running play (Noakes & Du Plessis, 1996; Duthie *et al.*, 2003). A study done by Duthie *et al.* (2006b) found that rugby union players regularly achieve 90% of their maximum velocity speed in a rugby game and back-line players perform more sprints than forwards. The recommendations for speed training from their study included the following: training for speed must include training efforts near the players' maximum velocity, the acceleration component of speed training can be done from different starting positions, e.g. walking or a striding start and overall the training must in general include high-intensity running, resistance training and technique adjustment.

Duthie (2006) suggests that players should do both specific speed exercises and general speed activities, together with normal fitness training drills. Grant *et al.* (2003) and Walsh *et al.* (2007) researched the effects of ball-carrying technique has on the speed of rugby players. The results indicated that in sprinting with the ball under one arm, the player can run faster than with the ball in both hands. The studies suggest that players should incorporate some sprint training while carrying a rugby ball, as this could benefit the early phase of the sprinting run and increase running efficiency when on

attack in a match. Bloomfield *et al.* (2007) researched effective speed and agility methods for random intermitted types of sports, and they indicated that the traditional programmed conditioning approach (prescribed amount of volume and intensity for practice sessions), is the best method, together with speed, agility and quickness (SAQ) training for improving speed. They also mentioned the importance of a fitness specialist for speed and agility conditioning to apply the correct training principles of overload and specificity. Table 2.5 represents a simplified example training programme for two methods of improving athletes' speed and agility.

Table 2.5: Six-week speed and agility conditioning example (Adapted from Bloomfield *et al.*, 2007).

Condition	Week1	Week2	Week3	Week4	Week 5	Week 6
Programmed conditioning approach	Introduction: Learn and develop basic speed, agility and quickness (SAQ)	Develop correct movement mechanics	Develop SAQ drills and complexity	Emphasis on resistance SAQ drills	Emphasis on SAQ reaction drills	Accumulate potential
Random conditioning approach	Play 2 basic small-sided games	Improve intensity of week1	Play 3 small - sided games with special rule to promote effort	Improve intensity on week 3	Play 4 small - sided games with special rules to promote effort	Improve intensity of week 5

Brughelli *et al.* (2008) agrees that by improving the agility of athletes, it can positively contribute to an increase in speed. The researchers further indicate that agility-specific exercises must include multi-directional movements of the body for the effective conditioning of athletes to increase agility performance. The reason for the positive effect of agility training on speed is the fact that, by doing agility exercise, it improves the moving ability of the body and specifically increase leg power, which is needed to increase an individual's leg turnover speed for the individual to run faster (Baechle & Earle, 2000; Sporis *et al.*, 2010).

Little and Williams (2007) suggest that work-to-rest ratios during sprinting must be altered to specifically develop the phosphagen system and suggest a ratio of 1:6 for 6x15m sprints, as a ratio of 1:4 may be too short for recovery during sprint training. Deutsch and Lloyd (2008) noted in their research that countermovement jumps before sprinting can negatively affect the performance of the sprint training, but loaded parallel squats can be incorporated into a complex training set-up without decreasing sprint performance. The study further concluded that sprint training and plyometrics training should be done in different training sessions.

2.6.2 Resisted speed training:

Resisted speed training is another method of increasing an athlete's speed, but is in some cases not recommended for improvement of short-distance speed (Kristensen *et al.*, 2006). The method requires that the external load used in resisted speed training must not be too heavy for the athlete, as an external resistance that exceeds ten percent may negatively influence the running mechanics of the player (Baechle & Earle, 2000; Cronin & Hansen, 2006). A literature overview article by Cronin and Hansen (2006) suggests that resisted sprinting is an effective method to train muscular power for the acceleration phase of sprinting. They further conclude that different resisted speed training methods result in specific adaptations. Weighted-vest training mainly maximises velocity adaptations, towing and uphill running improve stance duration, stride length and speed-strength (Baechle & Earle 2000; Cronin & Hansen 2006).

A study by Spinks *et al.* (2007) determined the effect of the long-term (period of eight weeks) resisted speed training in the form of weighted sled-towing on acceleration performance, leg power and acceleration kinematics. They found that this type of training is no more effective than non-resisted sprint training, but it provides a stimulus to the acceleration mechanics of the athlete and recruitment of the hip and knee extensors. Harrison and Bourke (2009) found, specifically in rugby union players, that resisted speed training can help to improve acceleration at the beginning of a sprint activity.

2.6.3 Speed assessment:

The regular assessment of an individual's speed, during different phases of a season can give an indication whether an athlete has maintained increases, or lost some pace. Speed programme can be adapted accordingly. An important factor to test for normal speed testing is speed endurance, Mclean (1992) in Noakes and Du Plessis (1996) described a protocol for such a field test. The test required players to complete as many as possible 100m sprints at a constant speed, which was predetermined by the player's maximum speed achieved in a normal 50m sprint. Resting duration of 20 seconds was allowed in between sprints. Duthie *et al.* (2006a) recommend from the findings in this study on speed, that the assessment and evaluation of speed must be done with the acceleration and velocity maximum components of sprinting over the 10, 20 and 30m for forwards and for the backs speed endurance assessment and longer sprint distances e.g. 60-70m must be used.

The 10m sprint test provides accurate information on individual athlete development of the acceleration phase and can detect small but significant changes in speed (Duthie *et al.*, 2006a). Young *et al.* (2008) agrees with above-mentioned findings and suggest an assessment distance of 40m, with recordings of time at the 10, 20 and 30m marks. Maximum speed qualities of athletes can be more accurately determined by a moving start, as opposed to a standing start. Bompa and Claro (2009) suggest that players' 30m speed must be tested by allowing both a standing and flying start, preferably with an electronic timing system.

Another test to assess running speed in terms of speed itself and kinematic variables (which can determine speed), is proposed by Makaruk *et al.* (2009), namely the 20m+20m running speed test, where an athlete has a 20m running start and completes another 20m after the run-up. Jarvis *et al.* (2009) assessed Welsh rugby union players' acceleration and speed over 10 and 40m and found forwards to complete the 40m sprint in an average time of 6.9 seconds, while backs completed it in 5.8 seconds.

Hanekom *et al.* (2008) measured the speed of rugby union players over a distance of 30 m. The sprinting times of the players were as follows: U/19 forwards' fastest average sprinting times were 4.8 sec, while backs were faster with an average of 3.8 seconds. Under-21 players' forwards fastest average time was 4.9 seconds and backs 3.8 seconds. For the other senior players, forwards completed the 30m sprint in 4.7seconds and backs in 3.9 seconds. Bompa and Claro (2009) indicate that better than average time for male players for the 30 m speed acceleration test is 4-4.20 seconds, 2-2.10 seconds for the 10m acceleration test and 3.40-3.60 seconds for the flying start 30m speed test.

2.7 TRAINING OF THE AEROBIC SYTEM:

Rugby players should have a good basis of aerobic fitness, as this is important to maintain a high working rate towards the end of rugby matches (Reilly, 1997a). In general, the conditioning of the aerobic energy system of an individual can lead to favourable circulatory and metabolic adaptation. Some of these adaptations include an increased cardiac output during exercise due to more effective blood flow to the muscles, which may lead to a faster removal of lactate from the muscles, therefore minimising the negative effect of fatigue associated with an increased H⁺ ion concentrations (Tomlin & Wenger, 2001). However, performing an excess of aerobic endurance running in a training programme for intermittent types of sports can induce overtraining and can also negatively influence neuromuscular and endocrine adaptations (Elliott *et al.*, 2007).

Stagno *et al.* (2007) suggest monitoring of the aerobic system training loads on individuals by means of a training impulse model (TRIMP). The model is calculated from mean heart-rate and intensity of training sessions, which can give an indication whether aerobic capacity of an athlete is sufficient, or whether it must be increased during the season. Burnley and Jones (2007) indicated that by training the aerobic energy system, aerobic functions such as exercise economy, lactate threshold and VO₂ max can be increased. This can lead to an improved performance by the player in a match situation as a well as properly developed aerobic capacity. Durocher *et al.* (2008) also notes the

importance of training of the aerobic system in the pre-season and highlight the importance of maintaining a certain level of intensity during training in the late phase of a season in order to maintain aerobic fitness of the athletes to prevent a decrease in performance. Stone and Kilding (2009) also state that aerobic system training should be done during in-season to keep athletes in a good condition. Development of the aerobic system of teams can be done through applying a traditional, classic or sport-specific conditioning model. The researchers further concluded that both the traditional and sport specific approach can favourably increase aerobic fitness if exercise intensity and volume is constant throughout the training programme. Before the aerobic system can effectively be applied to rugby union players, conditioning coaches must completely understand the aerobic exercise physiology of rugby players.

A study done by Scott *et al.* (2003) on elite rugby players in terms of the aerobic exercise physiology respectively in forward and back-line players found that back-line players tend to have a higher VO_2 max than forwards. They also concluded that their findings could be due to the different body types of players. This difference in the aerobic fitness profiles of backs and forwards should be addressed by position-specific aerobic conditioning programme. Hoff (2005) recommends that for improving maximal aerobic performance, the training programme must include exercises that increase maximum oxygen capacity, lactate threshold and running economy in the athletes. Kamenju *et al.* (2006) recommend that training-programme activities must be designed in such a way that it would elicit desirable levels of maximal oxygen uptake. Improvement in a player's maximal oxygen uptake can contribute to a basis for increasing a player's endurance capacity. This is achieved by long-duration exercises at 75% of a player's maximum oxygen capacity (Bompa & Claro, 2009).

It is a known fact that aerobic-endurance is a key factor in rugby, as a high-aerobic capacity can help a player to play longer at a high-intensity. This means multiple sprint performance is increased and it aid in recovery after high-intensity activity, thus the player can cope better with fatigue, which can negatively influence players' technical and tactical skills (Glaister, 2005; Duthie, 2006; Bompa & Claro, 2009).

Bompa and Claro (2009) prescribe some training parameters for aerobic-endurance that can be used by rugby conditioning coaches: training drills must increase heart-rates above 130 beats per minute to improve aerobic capacity, but must be in the range of 140-160 beats per minute. The duration of the drills must be between 3-10 minutes with a rest interval of 45-90 seconds, where the resting interval can be any low-intensity activity to facilitate biological recuperation.

2.7.1 Aerobic energy system assessment

Assessment of aerobic capacity of athletes is important to gain insight into fitness status of an athlete and to maximise their physical conditioning (Da Silva *et al.*, 2008). Rugby-specific performance tests for player fitness assessment are also performed to form part of a detailed training programme. These performance tests give a reasonably good indication whether the conditioning programme followed by the players is effective enough to obtain the necessary fitness goals set out by conditioning staff (Elloumi *et al.*, 2008). Tong *et al.* (2001) indicate that repeated treadmill sprinting can be used as a sport-specific measurement of speed, force and power of rugby players.

Aerobic capacity, as stated above, is important for a player's base fitness. The three tests that are primarily used to measure aerobic capacity and maximal aerobic power of players is the Cooper 12-minute test, 3km (1.5-miles) test and the multi-stage fitness test (beep test), (Scott *et al.*, 2003; Whaley, 2005; Bompa & Claro, 2009). With the Cooper 12-minute test, an individual is required to run as far as possible in 12 minutes (preferably around a 400m track). The distance covered during this time is substituted into a formula ($22.351d - 11.288$) from which the VO_2 max of the individual is determined in ml/kg/min (Whaley, 2005; Bompa & Claro, 2009). The other 3km test is a time trial, where the goal is to run the 3km as fast as possible. Targeted times are set specifically for rugby players of each position group to complete the time trial (Whaley, 2005; Bompa & Claro, 2009). The targeted time for completing the time trial run for forwards is between 11:30-12:00 minutes and for backs between 11:30 -11:45 minutes (Bompa & Claro, 2009).

Atkins (2006) indicates that the Yo-Yo intermittent recovery test can also be useful for intermittent type of sport, for it is used to assess the athletes' ability to recover from repeated high-intensity activities. However, one of the limitations of the test is the fact that it might underestimate the true VO_2 max of an individual, as it is estimated indirectly (Metaxas *et al.*, 2005). It was further noted in the study that the above-mentioned test is more specific to the type of activity done in a rugby league match compared to other aerobic tests. The test as described by Atkins (2006) consists of two running lines of 20m each, with a 5m recovery zone. Individuals must complete repeated sprints of 20 m, as the time to complete the 20m run decreases after each eight shuttles. After each speed increase for the eight shuttles, a 10-second recover jog is taken in the 5m zone. The total distance covered by individuals is then used to calculate performance on the test. There are also two levels on which the test can be done; one for pre-season testing purposes and level two for later in the season.

Castagna *et al.* (2006) investigated the correlation between the Yo-Yo intermittent recovery test level one and Yo-Yo endurance test level two for aerobic fitness. It was concluded that although the two levels were significantly related, basic physiological differences still existed between the levels. Test level one must be done in the pre-season as it can give an indication of aerobic fitness training loads and test level two during the season, as it gives an indication of an aerobic-anaerobic profile.

The multi-stage fitness test is one of the popular aerobic evaluation tests as it determines an individual's maximal aerobic capacity (Chaouachi *et al.*, 2009). It is also known as the 20m shuttle run test, where the individual has to run shuttles over a distance of 20m. The time to complete the interval runs gets shorter, indicated by an audio signal and the test is performed until the individual can not complete the shuttle in the required time (Scott *et al.*, 2003; Gabbett *et al.*, 2009a). An additional benefit of this test is that more than one athlete can be tested at the same time and minimal equipment is required to perform the test, making it an easy, time efficient testing tool in sport (Svensson & Drust 2005).

A reliable and valid proven alternative 20m multi-stage fitness test has also been developed by Piliandis *et al.* (2007) to assess aerobic capacity of athletes, namely the Hexagon Multi-Level Run Aerobic Test 10m. The test could be more sport-specific to the sprinting patterns in a rugby match, as the test requires some change of direction after each 10m sprint of the test. Jarvis *et al.* (2009) indicated the following results for rugby players who completed the 20m multi-stage fitness test in the pre-season phase: forwards reach an average level of 8.1 versus the backs, who reached a level of 10.2 in the test. The results of the study therefore indicate that back-line players have in general a higher maximal oxygen capacity than the forward players. The study by Quarrie *et al.* (1996) found similar findings on rugby players' VO_2 max, which was predicted from the 20m multi-stage fitness test. The researchers indicated that among the forwards, hookers reached the highest value of VO_2 max, followed by locks and loose forwards. Among the back-line players, the inside centres achieved the highest values, followed by midfield- and outside backs.

Functional field tests for rugby is also an effective means of measuring aerobic capacity, together with skills, and can also be applied as a conditioning strategy (McClean 1992; Roberts *et al.*, 2010).

2.8 COMBINATION TRAINING FOR ALL ENERGY SYSTEMS:

Traditionally, coaches would first focus on only increasing aerobic capacity of an individual and then switch over to a high-intensity, anaerobic kind of training to accomplish further improvement in fitness (Dennis & Noakes 1998). Both major energy systems can be simultaneously trained through applying certain training techniques. It is also important that the energy systems should be specifically trained in this manner by rugby players to optimise the effect of training on match performance by utilising each energy system effectively when needed. Table 2.6 summarises the energy system zones that a rugby training programme should incorporate to achieve maximum results from training. Specific attention should be given to include different technical and tactical

drills, as these drills can consist of a variety of rugby-specific activities (Bompa & Claro, 2009).

Table 2.6: The four intensity zones for rugby (Bompa (2006) in Bompa and Claro (2009)

	1	2	3	4
Training objectives	Lactic acid tolerance	Alactic system (ATP/CP)	Aerobic power	Aerobic compensation
Characteristics of training	<ul style="list-style-type: none"> - Combination of Technical and tactical drills - Tactical lactic acid tolerance training - Suicide drills 	<ul style="list-style-type: none"> - Combination of Technical and tactical alactic - Maximum speed/agility/power 	<ul style="list-style-type: none"> - Tactical VO₂ max drills 	<ul style="list-style-type: none"> - Aerobic compensation - Technical skill: accuracy of passing and kicking
Duration of technical and tactical drill	20-60/90 seconds	5-15 seconds	2-5 minutes or longer	5-10 minutes (several bouts)
Rest interval	3-5 minutes	5-7 minutes	2-3 minutes	1 minute
Heart-rate (bpm)	Above 180	150-170	Below 170	120-140
% of Total volume of training	40% progressively		40%	20%

2.8.1 Interval training:

According to Baechle and Earle (2000), interval training is done at intensity near an individual's maximal oxygen uptake and thus can improve one's VO₂ max. They further mentioned that exercise bouts should last for 3-5 minutes, with a work-to-rest ratio of 1:1. These authors further suggest that interval training can target specific energy systems, as illustrated in Table 2.7.

Table 2.7: Using interval training to train specific energy systems (Baechle & Earle 2000).

% of maximum power	Primary stresses	Typical exercise time	Range of exercise-to-rest periods ratios
90-100	Phosphagen	5-10seconds	1:12 to 1:20
75-90	Fast glycolysis	15-30seconds	1:3 to 1:5
30-75	Fast glycolysis	1-3 minutes	1:3 to 1:4
20-35	Oxidative	More than 3minutes	1:1 to 1:3

Rozenek *et al.* (2007) examined different physiological responses during interval-type training at different velocities related to VO_2 max. It is suggested that high-intensity interval training should be done at a 2:1 work-to-rest ratio, at 100 percent of the individual's VO_2 max, with an active form of recovery at 50 percent of their VO_2 max, to optimally develop and train both the aerobic and anaerobic energy system. The researchers further noted that a correct and balanced training volume should be induced on individuals to gain benefits from interval training. Billat (2001) indicated that interval training with a work-to-rest ratio of 1:4 can also increase the anaerobic capacity of an athlete. Another type of interval training can be done in the form of explosive jumping exercises. Examples of some general interval training as proposed by Lugar and Pook (2004:189) are: three-minute interval runs, where players run for three minutes and walk for two minute, completing 3-4 repetitions in one or two sets. These intervals develop aerobic and lactic systems as players run at threshold speed. Pyramid intervals (which replicate the different work-and-rest periods that commonly is experienced by rugby players) are another form of interval training. It stimulates the production of varying levels of aerobic and anaerobic energy. Interval training can also specifically focus on the development of athletes' speed-endurance capacity, as it can increase glycolytic and oxidative enzyme activities as well as various indices of anaerobic power, which can benefit the athlete (Baechle & Earl, 2000).

Speed-endurance intervals are drills similar to periods of exertion and running speeds in a rugby game. It helps players to cope with high lactic acid levels in games by making them used to it through these drills that elevate lactic acid levels higher or equal to the level that is experienced in games (Lugar & Pook, 2004). Examples of such speed-endurance drills according to Lugar and Pook (2004) are hills intervals; 233S and speed endurance interval combination, where hill intervals are ran at a 7.5-10 degree slope of 60-70m for four to six repetitions, with 2-3 minutes rest after a walk back off the slope and four minutes rest between the two sets. Track 233S are drills performed over 233 m. Players run at maximum speed, completing three to four repetitions with four to five minutes rest between these repetitions. Speed endurance interval combination is a drill that is ran over interval distances of 150, 100, 60 and 30m. Each distance has its own repetition range, rest duration and rest between sets (eg.150m is done four to six times for two sets, rest between repetitions for two minutes and rest between sets for three minutes).

Dupont *et al.* (2004) concluded that high-intensity interval training can improve aerobic speed, decrease 40m sprint times and therefore improve an athlete's aerobic and anaerobic performance. Stolen *et al.* (2005) indicated that that the aerobic endurance of a whole team can be increased over a short period by performing interval training and low-intensity training. The aerobic system can be removed from an aerobic training protocol, as it is already addressed in the normal skill-development training. Interval training can be done in such a way that it specifically focuses on enhancing the aerobic capacity of an athlete. It is achieved by performing interval runs shorter than 30 seconds, with active rest activities (at a lower intensity than in the interval runs) in-between repetitions (Elliot *et al.*, 2007).

High-intensity interval training has also proved to be useful for improving endurance performance in players and it can be useful as a transition method between aerobic, uniform activity and game-specific training (Price & Halabi 2005; Bompa & Claro, 2009). Aziz *et al.* (2006) also indicates the importance of high-intensity interval training, as the increase in aerobic endurance may help players during the late in-season phase for

important final matches. Interval training also holds benefits such as training the body systems to tolerate lactic acid build-up which therefore delays the onset of fatigue and stimulates an overall improvement of the aerobic system by the long-enough work duration at certain intensities (Bompa & Claro, 2009).

Stone and Kilding (2009) describe interval training as a traditional approach to aerobic conditioning. Guidelines for training according to this method and achieving results are that: the programme can be done for four to ten weeks, with two sessions a week and a recovery period of 48 hours between sessions. Running is performed at an intensity of between 85-95% of maximum heart rate for a maximum duration of four minute intervals and three minute rest periods in between. Sirotic *et al.* (2009) suggest that to, best prepare rugby players for the second half's physical demands of the intermediate game, repeated-sprint training can be used in combination with game-specific skills.

Haddad *et al.* (2009) also demonstrated the benefit of performing repeated intermittent supramaximal intensity exercises and how it improves cardiovascular fitness by having an effect on long-term cardiac autonomic activity. Iaia *et al.* (2009) also states that both high-intensity aerobic and speed endurance training will improve players' fitness and performance for sport that is highly intermittent of nature. Alizadeh *et al.* (2010) also indicate the positive relationship between performing interval-type training, such as repeated sprints, with different duration, distance, speed and type of recovery in-between on athletes' VO_2 max.

2.8.2 Tempo training:

Tempo training is important for athletes to incorporate in their training programme as it can improve both an individual's aerobic and anaerobic metabolism (Baechle & Earle, 2000). The intermittent tempo training method is commonly used by rugby strength- and conditioning coaches.

Bompa and Claro (2009) refer to tempo training as completing repetitions of 200-600m runs at a certain intensity (determined by maximum speed of players over the distance)

over the total distance. They also mentioned that tempo training closely represents the dynamic rhythm of rugby. It can be a useful method available to conditioners to move from all endurance training to more game-specific training. An example of a tempo training sessions will be six to eight repetitions of 400m performed by the players at 60% of their maximal effort, with four minutes rest between the repetitions.

2.8.3 Anaerobic energy system assessment:

As rugby requires a well-developed anaerobic capacity, regular assessment of it is necessary. Field tests are the most practical and time-efficient option available for coaches and provide a more specific evaluation of athletes, as the environment is the same as where the athletes participate in sport (Svensson & Drust, 2005; Castagna *et al.*, 2006).

However, the value of laboratory testing must not be excluded, as the study by Metaxas *et al.* (2005) indicates that field tests might not be as accurate as laboratory testing. The researchers further concluded that field testing is indeed easier to conduct and can be valuable for reassessment purposes of individuals. Aziz and Chuan (2004) recommend the running repeated sprint ability test for assessing anaerobic performance, as this test replicate the intermittent type of repeated sprints required in multiple sprint sports. The researchers indicate that the test requires players to run eight repeated sprints of 40m with 30 seconds rest in-between. The time to complete the sprints is taken of a “drop-off index” which is calculated from the times of the index to indicate the anaerobic capacity of an individual through their recovering the ability between repeated high efforts of sprints. Holloway *et al.* (2008) developed a triple 120m shuttle test specifically for rugby league players to evaluate their anaerobic endurance, illustrating that for reliable sport specific tests to be developed, the test must be validated with current accepted tests as in the case of the study. The Wingate anaerobic, 60-second test was used by measuring the players’ heart-rate and blood-lactate concentrations during both the aforementioned tests. Tinazci and Acikada (2009) developed a jumping test to measure anaerobic fitness of intermittent type of activities. The Hacettepe intermittent jumping test requires athletes to repeatedly jump five times for 15 seconds and resting for one minute

between jumping sets. Measurement of heart rate, recovery heart rate and maximal heart-rate were taken during the test and during the recovery time, indicating the fitness of the athlete.

2.8.4 Heart-rate as an indicator of the physiological demands of exercise:

Physiological measurements such as heart rate can determine in which fitness state an individual is and contribute to evaluation and description of the effectiveness of training programme (Sliwowski *et al.*, 2007).

Previous studies that focused specifically on determining the physiological demands of rugby mostly used heart-rate as an indicator of these demands (Morton 1978; Deutch *et al.*, 1998; Doutreloux *et al.*, 2002; Coutts *et al.*, 2003). A study done by Morton (1978) on rugby union players showed that backline players' heart rates ranged between 135-180 beats per minute during the rugby match, while the average heart rate was 161 beats per minute. In general, heart rate data on rugby union players to determine physiological demand is somewhat lacking. However, some studies have been done on the cardiac data of rugby.

A study by Deutch *et al.* (1998) found that props, locks and back-row forwards spent up to 20% of the match above 95% of maximum competitive heart rate and inside and outside backs spent significantly more time in moderate exertion of 75-84% of heart rate maximum. The conclusion the study came to was that forwards engaged in a higher overall intensity than backs, but backs tended to work for short periods at high intensities, with prolonged periods of rest. This study correlates with findings of Doutreloux *et al.* (2002), whose cardiac data showed that the forwards spent significantly more time carrying out intense exercises (higher than 85% of maximum heart rate) than the backs.

Coutts *et al.* (2003) and Gabbett (2005a) did studies on rugby league players, where they found mean heart rates between 152 and 166 beats per minute (bpm) in rugby league matches. In the study of Cunniffe *et al.* (2009), it was found that players achieved

an average heart rate of 172 bpm (performed at 88% of the player's maximum heart rate). According to Eniseler (2005), the measurement of heart rates is a valid and objective method to determine exercise loads during physical activities. However, as rugby is a contact sport, some logistical problems may occur, but Deutch *et al.* (1998) resolved this issue by enclosing the heart-rate monitors in protective strapping and many studies used it from then onwards. The use of heart rate can provide a useful index of overall physiological strain during a rugby game and quantify the total work performed in a game (Coutts *et al.*, 2003; Duthie *et al.*, 2003).

Heart rate can be used to describe and estimate the exercise intensity by the general linear relationship that exists between heart rate, work rate and maximal oxygen uptake (Achten & Jeukendrup, 2003). Achten and Jeukendrup (2003) also indicated that energy expenditure can be an indicator of the intensity of an exercise, as exercise intensity is defined as the energy expenditure per minute to perform work. The heart rate of an individual is used to estimate energy expenditure by determining the relationship between heart rate and maximal oxygen uptake, but this relationship may not be accurate during intermittent activity, as heart rate responds slow to a change in work rate, influencing the energy expenditure. Regardless of this fact, they concluded in their research that the most important use of heart-rate monitoring is to evaluate intensity of exercise.

Studies by Coutts *et al.* (2003) and Gamble (2004a) respectively supports the above-mentioned statement that heart-rate monitoring is an effective way of measuring intensity of activities. It also gives a good indication of cardiorespiratory fitness, making it a high-quality indicator and monitor of training status. It must be kept in mind that the above-mentioned relationship between heart rate and exercise intensity is influenced by factors such as training status, physiological factors such as cardiac drift and hydration status, environmental factors and time of day (Achten & Jeukendrup, 2003; Lamberts *et al.*, 2004). However, heart rate is sensitive to such conditions, meaning that it can be used for objectively verifying if individuals are working at, or above their physical capacity exercise threshold (Gamble, 2004a).

It is important to note that rugby as a sport has match variability, which differs from game to game, where ground conditions, weather conditions and tactics are applied to the game by the team and the referee handling the game can influence match activities (Duthie *et al.*, 2003; Quarrie & Hopkins, 2007). This makes heart rate an even more useful monitoring tool in the sport of rugby.

Heart rate variability can also be used as a tool to monitor overall stress induced by training and training programme can be adjusted accordingly (Berkoff *et al.*, 2007). Drust *et al.* (2007) also mentions that recording of heart-rates during match-play and training is a commonly-used method by sport scientists. By the objective evaluation of heart-rate response, it could further help in the process of determining and quantifying the physical effort given by the players during training sessions (Borresen & Lambert, 2008b). According to Bompa and Claro (2009), heart rate can also be used as an indicator of the level of fatigue player's experiences. This is because heart rate increases as fatigue increases in a player while performing a strenuous activity. Borresen & Lambert (2008a) point out, that while heart-rate measurement during exercise can indicate the total cardiac load on an individual, recovery heart-rate data can supply the individual with information on physiological adaptations that occurred due to the training programme that was followed.

A recent study by Dimkpa (2009) also states that post-exercise heart-rate recovery must be used more by exercise specialists to indicate and evaluate cardiovascular fitness of individuals, as it is already clinically proven.

2.8.5 Blood-lactate concentrations as an indicator of the physiological demands of exercise:

The use of blood-lactate concentrations in studies to indicate the physiological demands of rugby is fairly well documented. One of the earliest studies was done by Docherty *et al.* (1988), who found that post-match, mean blood-lactate concentrations of international players were 2.8 mmol/L, while Menchinelli *et al.* (1992) found mean blood-lactate concentrations of international players to be between 6-12 mmol/L.

McClean (1992) and Deutch *et al.* (1998) took blood-lactate samples during penalty kicks and injury stoppage and found mean values of 5.4-6.7 mmol/L and 5.1- 6.6mmol/L of first-division and U/19 players respectively. Deutsch *et al.* (1998) also related the blood-lactate levels of the players to the position they played. Higher blood-lactate levels occur more in forwards (reaching a maximum of 9.6 mmol/L) than backs (highest level of 7.5mmol/L). This corresponds with the longer involvement of forwards in high-intensity activities in a match.

Coutts *et al.* (2003) also found that blood-lactate concentration in forwards (8.5mmol/L) is higher than in backs (6.5mmol/L) in rugby league. These different ranges of blood-lactate concentrations in rugby games can be due to the fact that most of the studies differed in the time of taking the players blood-lactate samples. Fukuba *et al.* (1999) noted that blood-lactate levels continue to increase for several minutes up to peak value after cessation of exercise, due to the continued efflux from the previous active muscle and then the blood-lactate concentration declines back to baseline values. It is also important to note that blood-lactate concentrations decrease more rapidly during active recovery than during resting recovery, because active recovery means a faster rate of lactate removal from the circulation. A bigger use of lactate is a substrate for oxidative processes in the working muscle and endurance-trained athletes have increased oxidative capacity, meaning they will experience a faster rate of blood-lactate clearance (Fukuba *et al.*, 1999).

Varying workload durations can also lead to different blood-lactate response curves and measurements, which would affect the calculation of the exercise intensity corresponding to a specific blood-lactate threshold (Bourdon, 2000). Bourdon (2000) also reported that a rapid increase in blood-lactate concentrations may be an indicator of the point where there is a shift from oxidative to partly anaerobic energy metabolism. According to Krstrup and Bangsbo (2001), if high blood-lactate concentrations are found at half-time and after the match, it could indicate that the anaerobic system is highly stimulated during a game. However, Coutts *et al.* (2003) indicated that an accurate conclusion cannot be made about the contribution of anaerobic glycolysis to

performance based on limited blood-lactate determination. Interpreting and measurement of blood-lactate concentrations during competitive matches, factors such as individual fitness, emotional stress, time of measurement and environmental conditions can affect the outcome of the results (Coutts *et al.*, 2003).

However, a study by done by Kin-Isler (2006) indicated that the time of day that the blood-lactate measurement is taken during and after supramaximal exercise does not affect the lactate's concentration. However, in the same study it is indicated that an elevation in body temperature during exercise may contribute to an increase in enzyme activities that can be linked to increased lactate production. At high-intensity exercises, lactate accumulates due to the result of lactic acid production being greater than the removal of it. It is well known that at heavier exercise intensities at 50–80% of VO_2 max blood-lactate increases compared to rest, as lactate levels increase with the metabolic work rate of the body (Billat *et al.*, 2003).

Using blood-lactate concentrations to indicate a representation of the overall demand of a game can be difficult, as it may not relate to specific passages of play and intensity activity, because periods of low-intensity allow blood-lactate to be metabolised (Duthie *et al.*, 2003). This effect is illustrated by figure 2.1, indicating the fluctuating levels of blood-lactate concentrations during a complete rugby match.

Eniseler (2005) indicated that lactate testing is after all a useful tool for evaluating endurance performance as an indication of the contribution of the anaerobic glycolytic energy system, prescribing exercise intensities for athletes and monitoring training adaptations.

McMillan *et al.* (2005) agree and state in one of the conclusions of the study that lactate assessment is useful for determining endurance training adaptations. Price and Moss (2007) also describe that athletic performance duration can be associated with the blood-lactate concentrations of athletes. Coutts *et al.* (2009) mention in his study that blood-lactate concentrations may represent an accumulated response to various

previous high-intensity activities performed by individuals. Within this study, measurement will be taken pre-and post match analysis, as well as during half-time, which will attempt to represent an overall indication of blood-lactate concentrations that players experience during the match. During the practice session, lactate measurements of participants will also take place before and after, as well as in the middle of the training sessions.

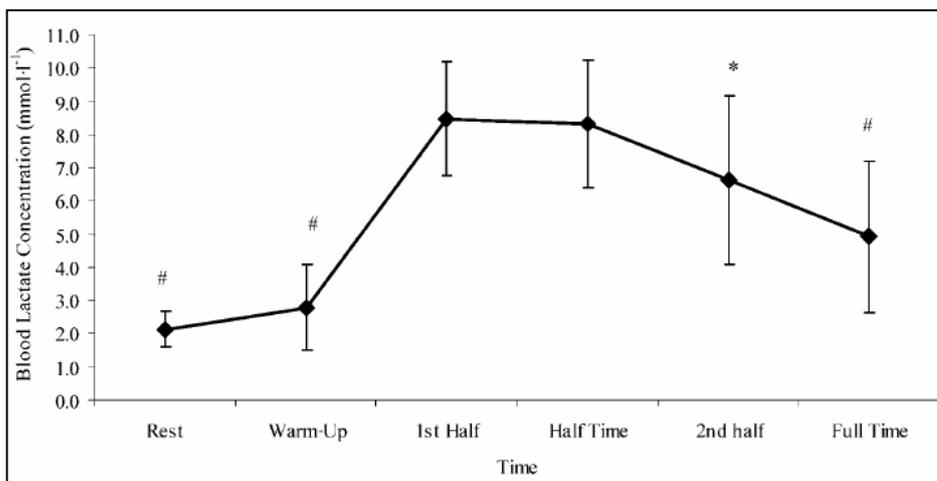


Figure 2.1: Mean blood-lactate concentration during a semi-professional rugby league match. # Significantly different to the first half, the second half and half-time ($P < 0.05$). *Significantly different to first half ($P < 0.05$) (Coutts *et al.*, 2003).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

It is well established that heart-rate and blood-lactate concentration are good indicators of physiological demands of exercise and are used in this study to determine the demands of rugby matches and practice sessions. The aim of the study is therefore to determine if heart-rates and blood-lactate concentrations of club rugby players are the same during rugby matches and practice sessions. The aim of this chapter is to explain and describe all the measurements used in the study, namely heart-rate tempo and blood-lactate concentration. The practice sessions will also be described to gain some insight on the kind of training that was conducted by the participating club.

3.2 STUDY POPULATION

A single experimental group of male 21-year-old rugby players from Tuks (University of Pretoria) rugby club participated in this study.

3.3 TEST PROTOCOL

The test protocol consisted of heart-rate and blood-lactate measurements of 15 rugby playing subjects. All measurements is taken from the same rugby team, during 3 rugby practice sessions and during one of the rugby union matches played by the U/21 Tuks rugby team in the local Blue Bull Carlton league.

3.3.1 Practice sessions

The rugby practice sessions during which measurements were taken of the team were prior to the official rugby game in the late pre-season phase of training. The training sessions represented the typical practice activities and drills of the participating team. The first part of the three practice sessions started off with some fitness training consisting of two sets of five meter repeated sprints of 6 repetitions, 30 seconds running and 30 seconds rest, with a two minute rest period between the two sets.

The other fitness drills in the first part of the training sessions consisted of sprinting 50m every 20 seconds for eight repetitions, in three sets, with a rest period of two minutes between sets. The last exercise started off with ten metres sprints every five seconds from a downward position. Ten repetitions were done in a set for a total of ten sets. The next part of the training session consisted of technical and tactical drills, which included semi-contact game plan structures and strategies done at high intensities. Ball drills and running grids to improve players' overall rugby skills were also performed. Rest during these drills was kept at a minimum for testing purposes, to increase players' fitness and improve concentration levels for match situations.

3.3.2 The rugby match

The team played a pre-round match home game against another highly-competitive U/21 rugby club team, which also participates in the Blue Bull Carlton league. The rugby match lasted 70 minutes and it was arranged that the players who participated in the study stayed on the field for as long as possible. Substitution was only made for injuries. Half-time lasted six minutes and a total of seven injury stoppages. The night game was completed during March 2010, in a mild playing environment. Fluid was also readily available during the game for adequate hydration levels of the players, as dehydration can increase physiological strain and lead to a decrease in performance (Sirotic *et al.*, 2009).

3.3.3 Heart rate

Measurements of the heart rates of the 15 subjects in the study were taken during the practice sessions and the club rugby match. The real-time telemetry heart-rate system (Hosand®, TM 200, Italy) illustrated in figure 3.1, was used to record heart rates (in beats per minute (bpm)) every five seconds throughout the sessions and match to get the average and peak heart-rates of the subjects during above-mentioned situations. The telemetry system that was used works through a transmitting device (TX 200, Italy), which is placed into a pocket of a specially designed vest, worn by the subjects under their rugby jerseys. The transmitting device intercepts heart-rate signals from a heart-rate monitor chest strap (Polar). The signal is received through an antenna connected to

a computer (PC), where a graphical representation of the heart-rate of the subjects can be seen. Heart-rate monitors were also checked regularly during the practice sessions and match to ensure that it works properly for recording the heart-rate data.

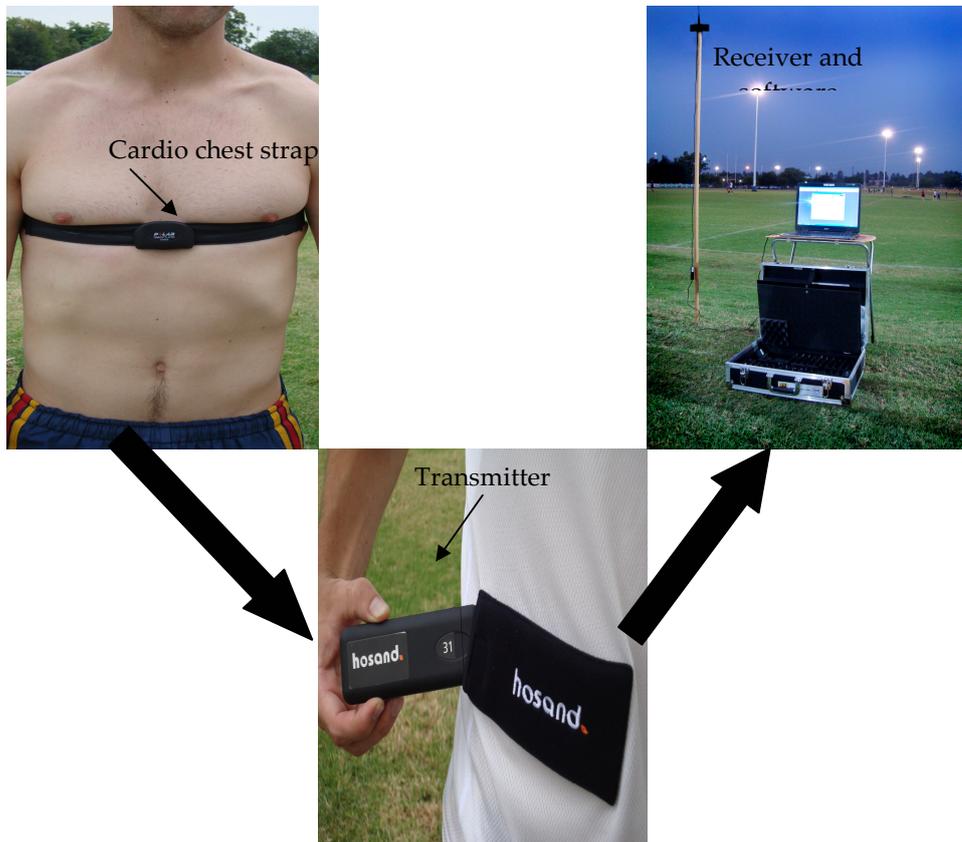


FIGURE 3.1: Hosand®, TM 200 real time heart-rate monitor system

3.3.4 Blood-lactate concentration

Blood-lactate concentration measurements in the study were done according to the method used by Rampinini *et al.* (2007). The lactate concentrations are taken from the capillary blood vessel of the athlete's earlobe to obtain a sample of 5mL whole blood. A single-use disposable lance is used to make the incision in the ear lobe to draw the sample. The blood drop is placed on the tip of the test strip (Lactate Pro™ test strip) and lactate concentrations are immediately analysed through the chemical reaction that

takes place inside the portable lactate analyser (Lactate Pro Test Meter, Arkray, Japan), which expresses it in milli mol per litre (mmol/L).

The portable blood-lactate analysers used in the study are reliable and valid for athletic testing, as reported by Mclean *et al.* (2004). The blood samples were drawn before, during and after the practice sessions. In the rugby match, samples were drawn before warm-up, during half-time and after the match were completed. The same order of measuring the subjects was followed in all circumstances when lactate measurements were taken. Before warm-up in the practice sessions and match, all 15 subjects' blood-lactate concentrations were measured. In the middle of the practice sessions and during half-time in the match, 7 subjects lactate concentrations were measured. These subjects included forwards nr 1, 4, 7 & 8 and back-line players' nr 9, 11 & 13. After the match and after the practice session, the other eight subjects was measured, forwards nr 2, 3, 5 & 6 and backs nr 10, 12, 14 & 15. These measurements were done in this particular way to collect peak blood-lactate data that represented the overall physiological stress placed on rugby players after the most recent activity performed during practice- and match situations.

3.3.5 Statistical analysis

The data analysis of the study had the following aims:

- To determine if there is a significant difference ($p < 0.05$) between heart rate and blood lactate during a match and practice sessions.
- To determine if there is significant differences ($p < 0.05$) between the two different circumstances (practices and match) for forward- and backline players in terms of average heart-rate and peak blood-lactate concentrations.

The statistical data analysis procedures that were used in the study included:

Descriptive statistics:

Descriptive statistics are used to describe data. The means, standard deviations, minimum and maximum scores for all variables measured were determined. An indication of the physiological demands placed on the rugby players could be indicated through descriptive data.

Inferential statistics:

Inferential statistics sample data is used to draw conclusions on the population group or groups from which sample measurements were obtained from (Sheskin 2000).

Dependent t-test (Paired t-test):

When data is collected twice on the same subjects, an analysis will be done with a dependent sample t-test, to test whether a significant differences exists between the mean of two sets of scores (Thomas & Nelson, 2005). In this study the test was used to determine the significant differences between match- and practice sessions for the two variables measured.

Independent t-test (Parallel test):

This test is used to determine whether two samples differ reliable from each other (Thomas & Nelson, 2005). In this study it was used to determine whether significant differences ($p < 0.05$) within the forwards and backs group exist to indicate positional differences.

All significant differences were reported at the five percent level of significance, with all graphs representing the mean values based on statistical analysis that was used.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

In this chapter the results from the physical testing will be discussed according to the aim of this study. The first discussion will describe the total physiological strain on club rugby players during matches and practice sessions, together with a comparison drawn between the physical demands during a rugby match and typical training sessions. Another comparison that will be made is the differences of the physiological strain placed specifically on the forwards and back-line rugby players in the two different situations. The last comparison will be between the forwards and backs to indicate whether a difference in physical stress exists in these two groups.

The group's data was statistically analysed with descriptive statistics (means and standard deviations). Significant difference was determined by the dependent t-test with significant difference set at p-value of lower than 0, 05.

4.2 PHYSIOLOGICAL DATA OF THE TUKS RUGBY CLUB PLAYERS

The club rugby team group consisted of the Tuks U/21A team (n=15) and was tested in the pre-season of the local 2010 rugby season. The players were tested according to the methods used by Hasegawa (2005) and Rampinini *et al.* (2007) for heart rate and blood-lactate measurements respectively.

Table 4.1: Descriptive statistics for Tuks under-21 rugby players in terms of heart rate and blood-lactate concentrations during different activities

Variable	Mean	Std Dev	Minimum	Maximum
Average heart rate in practice session (bpm)	138.33	4.81	131	147
Average heart rate in rugby match (bpm)	154.40	8.53	140	170
Peak blood-lactate levels in practice (mmol/l)	4.93	1.83	1.70	7.60
Peak blood-lactate levels in match (mmol/l)	5.39	2.44	2.0	13.30

Table 4.1 represents the descriptive statistics of the whole team's physiological data during the practice sessions and rugby match. Significant statistical differences were found between mean heart rate in the rugby match and practice sessions. The highest mean heart rate was observed in the match (154.40 ± 13.53) and is much higher than the highest mean heart rate observed in the practice sessions (138.33 ± 4.81). There are large differences between minimum and maximum values for the mean heart rate achieved in practice and match situations, which means there was a fluctuation between players' data, with standard deviations of 4.81~5bpm for the practice sessions and 8.53~9bpm for the rugby match.

These differences can be due to individuality and individual effort given during the two different types of activities. These differences can further be explained due to factors that influence performance in a match, such as game tactics that is applied and motivation to win the match (Bouhle *et al.*, 2006). It is also an indication that heart-rate values for U/21 club players vary during practice sessions, as well as in a rugby match situation.

The heart rates achieved during the team's practice sessions were low. A study by Lambert *et al.* (1998) on long distance runners indicated that the heart rates of athletes responded differently during competition than in training.

These heart-rate differences could not be explained by the terrain they ran on or added psychological stress. Another explanation for the low heart-rate values in the practice sessions is the fact that more closed skill drills were performed in the practice sessions in the study than open-skill drills, which has been proven to elicit significantly- higher heart rates in athletes (Farrow *et al.*, 2008).

No significant differences were found between peak lactate measurements in the match (5.39 ± 2.44) and practice sessions (4.93 ± 1.83). The study by Ekblom (1986) reported lactate levels for soccer players during a match to reach levels of 7-8 mmol/l, as soccer is also an intermittent type of sport. Although the values were higher in the sport, it can be due to the different running patterns in a soccer game. Mclean (1992) found blood-lactate levels of international players during a match to be between 5.8 and 9.8 mmol/l. Duthie *et al.* (2003) also indicate that blood-lactate levels of rugby union players during matches are 2.8 and 9.8 mmol/l. These differences in lactate results of the above-mentioned studies can be due to the timing of taking the blood samples, which influences the value as well as the standard of players (ranging from 1st division to elite rugby players). Coutts *et al.* (2003) found a slightly higher mean blood-lactate of 7.2 mmol/l in rugby league players in a match. The difference in lactate levels could be due to different playing levels of the players.

The review study of Gabbett (2005a) also indicates similar heart rate and blood-lactate data, as the study was on amateur rugby league players (similar to club level as in the current study). They achieved heart rates of 152 bpm and peak lactate levels of 5.2 mmol/l in a match, which is similar to the finding of this study on heart rate and blood-lactate. Mean average heart rates in elite junior Australian rule football matches were 173 bpm in the first half and 163 bpm during the second half of the match. Blood-lactate concentrations of these players ranged from 8.2-9.2 mmol/l (Veale & Pearce, 2009). In

comparison to the current study, the differences in heart rate and blood-lactate concentration could be due to the difference in the level of participation, as well as the difference between the sport of rugby union and Australian rule football. In Australian football the average amount of running done during a match (10-16km) is more than in a rugby union match, where an average distance of 5-8km, is covered by players (Deutch *et al.*, 1998).

The study of Tessitore *et al.* (2006) found mean lactate concentration of 3.7mmol/l for older basketball players, aged between 55 and 64 years, during a basketball match. The lower lactate values achieved are most likely due to the age of the players. In the study of D'artibale *et al.* (2007), which focused on motor cyclists' heart rate and blood-lactate levels in official races and qualifying sessions', he also found no significant difference between the two situations in terms of session's peak blood-lactate levels. In the qualifying session an average peak lactate level of 5.2 mmol/l and 6.0 mmol/l in the race was found. These similar blood-lactate concentrations achieved could be due to the high physiological stress placed on the bike riders.

The study of Rampinini *et al.* (2007) indicated a variety of blood-lactate levels for soccer players playing different small-sided soccer games for aerobic interval training, which ranged between 3.4-6.5 mmol/l. Again the similar lactate values are due to the fact that small-sided soccer games are also classified as an intermediate type of sport with similar high-intensity activities in a game, followed by lower intensity activities, creating similar physiological responses. Robert *et al.* (2010) found that a rugby specific exercise protocol done on university's standard rugby union players, with an average age of 21 years of age, elected a mean heart-rate of 158 -160 bpm during the exercises and mean blood-lactate concentrations of 4.6mmol/l. The above-mentioned study was done on a similar population group of players as the present study, which could explain the correlating findings between the two studies.

The general observation that heart rates are higher in a competition situation corresponds with other studies in different sporting codes. The reason for similar results amongst the studies could be that competition circumstances do indeed impose a higher physiological load on athletes. Some of the studies to illustrate this fact are mentioned below. Eniseler (2005) indicated in soccer; match situations elicit significantly higher mean heart rates than in various training activities. In friendly matches the average heart rate of the players was 157 bpm, during the modified soccer game 135bpm and during the technical session 126 bpm. Greig *et al.* (2006) examined physiological and mechanical responses of semi-professional soccer players to soccer specific intermittent exercises. He also indicated lower physiological responses during soccer exercises than reported in a soccer match, as mean heart rate responses between 125-135bpm were reached in the activities done by the participants in the study.

The study of Jones and Drust (2007) on small-sided soccer games indicated mean heart rates of 175bpm for the four vs four player games and 168 bpm for the eight vs eight player soccer match. Barbero-Alvarez *et al.* (2008) indicated a mean heart-rate of 174 bpm during small-sided five-a-side soccer matches and at no time during the game were the players' heart-rates below 150 bpm. The higher heart rates achieved in the two above-mentioned studies, during the small-sided soccer game studies maybe due to the higher pace and intensities the game is played at, as well as few rest periods for the players due to the number of players involved in a match (Barbero-Alvarez *et al.*, 2008).

Bouhle *et al.* (2006) also found that Taekwondo athletes had a more significant rise in heart-rate during competitions than in normal training. A mean heart rate value of the athletes was 197 bpm at the end of the competition and blood-lactate concentrations of 10.2 mmol/l was detected. Although Taekwondo is an intermittent type of sport, the same as rugby union, the results differ, because the duration of Taekwondo competitions is three rounds of three minute bouts, with one minute recovery between rounds.

A study by Baillie *et al.* (2007) on heart rates of competition Highland dancers found a significant difference between competition heart-rates and training, as a mean heart rate of 195 bpm was achieved during competition and only 151 bpm during training. The high mean heart rates achieved in the aforementioned study, compared to the present study, is that competition dance routines are only between two to three minutes long, therefore higher heart rates can be sustained for a short period than in a rugby match, which lasts 40 minutes each half. Montgomery *et al.* (2010) found that mean heart rates of U/19 basketball players were 162bpm during a game, while during different practice drills, which included defence drills, offence drills and a five-on-five game, mean heart-rates ranged between 147-152 bpm.

The mean heart rates during practice is slightly higher than the current study's mean heart rates of 131-147bpm during a practice session. The difference could be due to differences in practice session between the two sports.

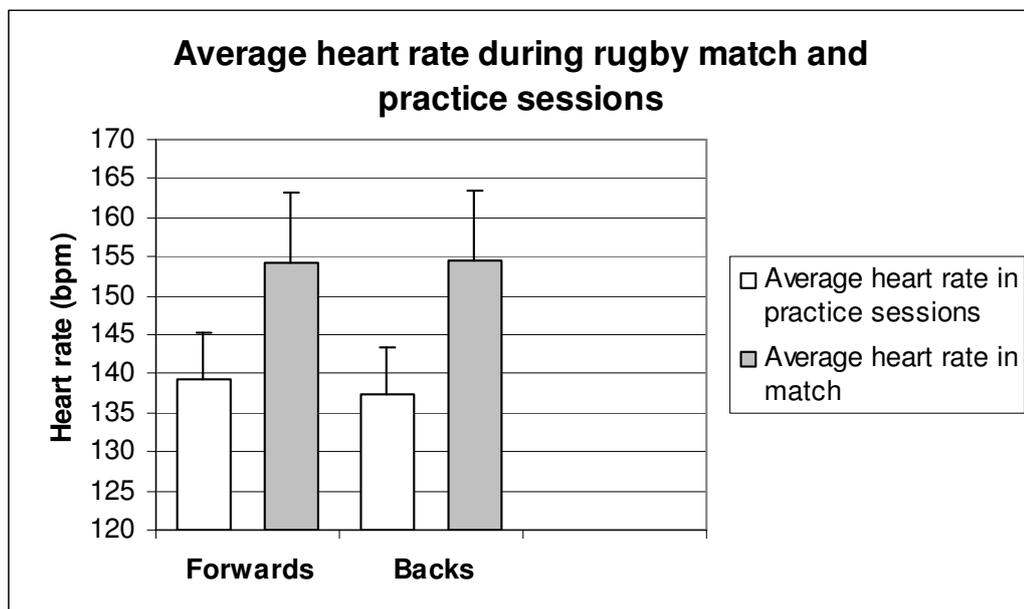


Figure 4.1: Heart rates during rugby match and practice sessions

(Error bars represent standard deviations).

Figure 4.1 indicates the heart-rate data of forwards and back-line players respectively during practice sessions and the match.

Forwards achieved a mean heart rate of 139.25 ± 5.18 bpm and 154.25 ± 7.97 bpm for practice and match respectively. Backs completed the practice sessions and the match with an average heart rate of 137.29 ± 4.50 bpm and 154.57 ± 9.54 bpm respectively. Differences of statistical significance were found for both the forward and back-line players between these average heart rates during the practice sessions and the match. Between the forward and back group no statistical significance could be found for average heart rate in practice sessions and the match. In the practice session the same total number of fitness drills and distances to run were allocated to both the forward and backs groups.

In the rugby match, mean heart-rate values were also similar. However, these results do not reflect the findings of previous studies. As Doutreloux *et al.* (2002) found, mean heart-rates of forwards to be 180 bpm; Deutch *et al.* (1998) indicated that forwards had a higher mean level of effort in a rugby union match than back-line players, and Duthie *et al.* (2003) state that forwards indeed tend to perform a greater total amount of work in a match. However, these studies were done on elite players and Coutts *et al.* (2003) indicate that a higher standard of rugby can lead to increased intensity at which rugby is played, therefore the intensities differ at club level rugby. Another reason for the result of no difference between forward- and back-line players' heart rate, which does not correspond with the above mentioned studies is the fact that forwards' and backs' role in a match are becoming more interrelated in modern day rugby. The general speed at which the match is played is faster, due to the ball being more in play (Jarvis *et al.*, 2009).

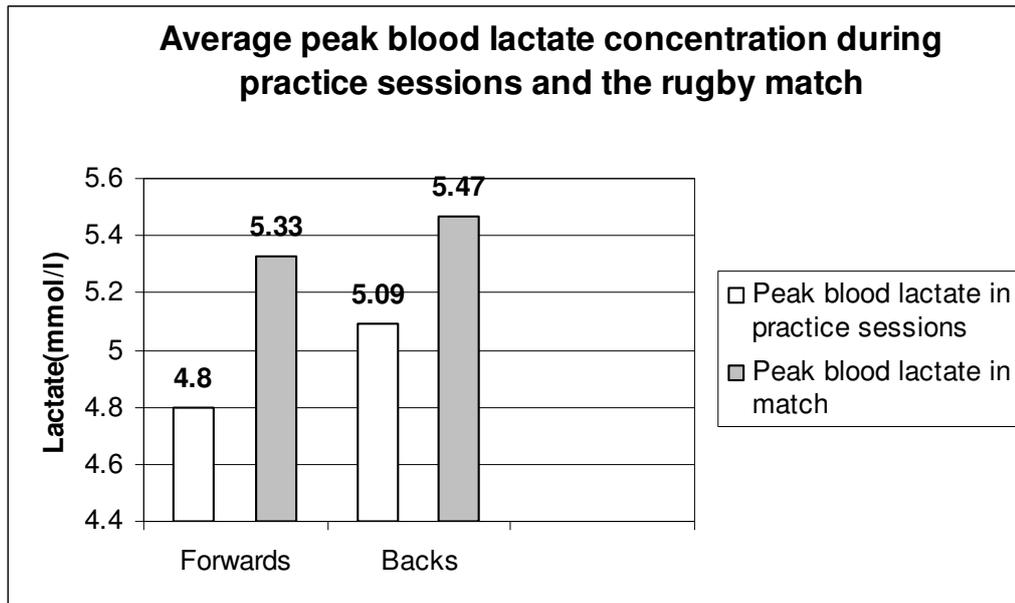


Figure 4.2: Peak blood-lactate levels during practice sessions and the rugby match

In Figure 4.2 blood-lactate concentration values can be seen for both groups, the forward and back-line players. No statistical significant differences were found for both groups between the rugby match and practice sessions.

There were also minimal differences in values between the forwards and back-line players in both the practice sessions and the match. Forwards (4.8 ± 1.89) vs Backs (5.09 ± 1.90) in the practice sessions and forwards (5.33 ± 0.49) vs backs (5.47 ± 3.69) in the match. Important to note is that no statistical significant differences ($p < 0.05$) were found between the forwards and backs groups for peak blood-lactate concentrations during either practice or match, as illustrated by Figure 4.2, between the two groups' lactate values. Similar findings on differences between forward and backline players were indicated by other studies, illustrating the small differences of mean blood-lactate concentration values between forwards and back-line players in rugby, as the same energy system is used by all playing positions.

The study of Deutch *et al.* (1998) could also not establish a significant difference between forward and backs for mean blood-lactate levels during an elite U/19 rugby match, but a difference was found as forwards reached a mean blood-lactate reading of 6.6 mmol/l and the back-line players' 5.1 mmol/l. Coutts *et al.* (2003) found mean lactate values differ with 2.0mmol/l between rugby league forwards and back-line players, as forwards tend to have a higher concentration of 8.5 mmol/l and 6.5 mmol/l for the back-line players.

In the current study, the mean blood-lactate level of 5.33 mmol/l that was achieved in the rugby match is firstly an indication that a considerable amount of anaerobic glycolysis energy system was used by the players, as high blood-lactate accumulation levels of 4mmol/l and more are associated with glycolytic anaerobic metabolism (Swart & Jennings, 2004; Chatterjee *et al.*, 2005). Performing repeated high-intensity activities is also associated with high muscle lactate concentrations. Bouhlef *et al.* (2006) also indicated that a high rise in heart-rate and blood-lactate in a competition situation is linked with anaerobic metabolism.

Coutts *et al.* 2003) further state that the higher the blood-lactate level of the individual, the more of the energy supply is from the anaerobic energy system. As blood-lactate concentrations are associated with the most recent activity done by an individual, which is a reason for the high blood-lactate levels that were achieved, together with the intermittent nature of rugby, the aerobic energy system can not be excluded as a contributing energy source.

Guevèl *et al.* (1999) suggest that mean blood-lactate concentrations in the range of 5-6mmol/l can be an indication of both anaerobic and aerobic metabolism. Spencer *et al.* (2005) further indicate that by performing successive repeated high-intensity activities, which are the case in a rugby match, can reduce the use of anaerobic metabolism as an increased contribution of the aerobic system take place. The total duration of a whole rugby match can also be linked to the aerobic energy system, as the duration of an activity can also determine which energy system is used (Baechle & Earle, 2000).

With a mean heart rate of 154 bpm that was achieved by the players, is another confirmation that aerobic metabolism was present in club rugby players during the match, as Baillie *et al.* (2007) indicate that a heart rates of 152bpm is associated with the aerobic energy system. The present study's findings correlate with other researchers' studies in the field of physiological demands, particularly which energy systems are used by the players in the sport code of rugby union, which can be summarised as a contribution of both aerobic and anaerobic metabolism during the different activities performed by players on the field (Deutch *et al.*, 1998; O'Conner 2004; Gabbett, 2005a; Deutch *et al.*, 2007).

4.3 CONCLUSION

The results of the study were discussed in two parts. Firstly the physiological stress experienced by the whole rugby team during practice sessions and a rugby match and then according to different playing positions, namely forwards and back-line players in the two different situations, with a comparison between the two groups. A further indication was also made about which energy systems are used by club rugby players, according to the findings of the study.

Although some skill-based conditioning drills were included in some of the practice sessions, intensities of a rugby match could not be mimicked overall. Gabbett *et al.* (2008) indicates similar blood-lactate concentrations for skill-based conditioning games, (5.2mmol/l) as in this study where mean peak lactate values reached 4.9mmol/l.

Drust *et al.* (2007) also indicate that it is difficult to mimic soccer match situations in practices, as there are various activities of different intensities and the element of mental focus of players differ in matches. However, the study by Nicholls *et al.* (2009) on professional rugby player's psychological engagement in matches and training indicated that most players had an increase in concentration levels during training, due to the fact that the players' must memorise game plan strategies.

The impact of rule changes on the game and the change in patterns of play must also be kept in mind as Eaves and Hughes (2003) suggest that rugby union becomes more professional as the match intensity increases in specific phases of play, which leads to overall faster match play. Williams *et al.* (2005) state that rule changes have had an influence on the time the ball is in play in a match, which leads to more match play taking place and creating more continuity during a game, increasing match intensities.

Walsh *et al.* (2007) mention that rules have an influence on the game of rugby, as it can result in more overall running by players, which can increase the physiological demands on the players. Gabbett *et al.* (2008) also clearly indicate that rules that change can lead to a change in the physiological demands placed on the rugby players. The comparisons between studies on physiological data can therefore vary. Another difficulty in the comparison of the previous study, specifically on rugby players, is the fact of the difference in playing standard. Sirotic *et al.* (2009) indicate that, although the same physiological systems and game-specific skills are used, a higher physical demand can be expected on the elite level of participation.

In conclusion, the rugby match placed considerable more physiological stress on the whole rugby team during the match as in the practice sessions. The forward and back-line players also experienced the same amount of higher physiological stress during the rugby match than in the practice sessions. It is important that training induces enough physiological stimuli, as a high level of cardiorespiratory fitness may contribute to an improved playing ability (Gabbett *et al.*, 2008).

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

The aim of the study was to investigate specific physiological demands among club rugby players by collecting data during rugby matches and practice sessions by means of heart rate and blood-lactate measurements, with the goal of comparing the physiological strain placed on players during the above-mentioned situations. This chapter will include: a summary of the main results found on the physiological demands of rugby. Conclusions will be according to the goal and objectives of this study, together with recommendations for specifically fitness training for rugby union players.

5.2 CONCLUSIONS

The main objective of the study was to determine physiological stress placed on club players during rugby matches and practices. The hypothesis of the study was that heart-rate and blood-lactate concentrations are lower during practice sessions than in rugby matches. It was established in this study that U/21 club rugby players' blood-lactate concentration and heart-rate data do indeed indicate the primary use of the anaerobic energy system as reported by previous studies on rugby union players on different participation levels. High peak blood-lactate levels were reached by the players in the rugby match and practice sessions. Due to the use of anaerobic glycolysis for energy in the rugby match, the metabolic work rate increased due to high-intensity efforts given by players in tackling and static pushing activities in the rucks and mauls (Duthie *et al.*, 2003; Billat *et al.*, 2003).

Swart and Jennings (2004) also indicate that whole-body movements elicit higher blood-lactate levels than only upper-body movements, which is the case in a match where players do use multiple limb movements to play the rugby game, as it involves running, pushing and physical contact activities. In practice sessions, high blood-lactate values were reached due to the nature of the practice sessions, where specific exercises were

done to improve the players' anaerobic capacity to cope in a rugby match. The heart-rate values achieved during the match also highlighted the intermittent type of activities performed during a rugby match, as indicated in previous studies on rugby players.

Although the rest periods between exercises in the practice sessions were kept at a minimum, rest periods between bouts of exercise in practice would not accurately represent the rest periods and phases in the rugby match, therefore it could explain the lower heart rates achieved by the players during practice sessions than in the match. It leads to the conclusion on another objective of the study, namely whether the club players optimally prepare themselves for matches in the practice sessions. Although the correct energy system was trained during practice sessions, which can be seen in the blood-lactate concentrations that were similar, the overall intensity in the practice sessions was too low to optimally prepare players for the required match fitness and intensities. One of the main purposes of practice sessions is to condition players to tolerate the metabolic conditions experienced during a rugby match to perform in an attempt to win the match (Gamble, 2004a). The findings of this study indicated that there was indeed a correlation in blood-lactate concentrations during matches and practice sessions. However heart rates significantly differed between the two situations.

5.2.1 Limitations of the study

There were some limitations to the current study. The sample size used in the study was quite small meaning that the players could significantly differ from each other, due to individuality. More rugby matches could have been included for evaluation purposes to achieve a more general representation of the club rugby match conditions. However, time constraints, variation in fitness levels of the players as well as variety between matches were also a factor which could influence results. Distances covered during the rugby match and practice sessions were also not measured. The generalization of the data may therefore not represent an accurate description for physiological stress experienced by all U/21 club rugby players.

5.3 RECOMMENDATIONS

The following recommendations are made from the results obtained in the study. The data from the study can provide valuable and useful information for coaches and conditioners on the physiological requirements for U/21 club rugby players during practices and rugby matches. It can furthermore give direction for further studies:

- Fitness, as well as technical and tactical drills used by coaches, should be monitored during practice sessions to ensure optimal preparation for rugby matches, as match-type activities and intensities must be mimicked in practices for match-specific fitness to occur, contributing to the effectiveness of a rugby-conditioning programme. More insight can also be gained on how individuals respond to training activities. Fitness drills can be changed instantly by increasing or decreasing intensities, as well as adapting recovery time in between.
- Coaches should also ensure that players' give the maximum effort during training activities to optimise team performance in a match, as every individual in a rugby team contributes to the overall match performance;
- Game-specific training should be incorporated more into club player's practices to achieve similar heart-rates than in matches, because by incorporating such a training method, a more competitive environment can be created which can lead to increased physiological stress. As in the present study average heart rates during practices sessions were not as high as in the match. Game-specific kinds of training may be more effective than using traditional conditioning methods only;
- Future studies are needed to be conducted on club level players for development and extension of the knowledge of coaches to ensure an improvement in the

quality of the club rugby player's fitness for an overall increase in the standard of club rugby in South Africa; and

- More rugby clubs may be researched to establish an accurate overall indication of physiological stress experienced by club players of a variety of clubs during training and match situations.

REFERENCES:

ACHTEN, J., & JEUKENDRUP, A.E. (2003). Heart-rate monitoring: Application and limitations. *Journal of Sport Medicine*, 33 (7): 517-538.

ALIZADEH, R., HOVANLOO, F. & SAFANIA, A.M. (2010). The relationship between aerobic power and repeated sprint ability in young soccer players with different levels of VO₂ max. *Journal of Physical Education and Sport*, 27(2): 86-92.

APRIANTONO, T., NUNOME, H., IKEGAMI, Y. & SANO, S. (2006). The effect of muscle fatigue on instep kicking kinetics and kinematics in association football. *Journal of Sports Science*, 24(9): 951-960.

ARGUS, C.K., GILL, N., KEOGH, J., HOPKINS, W.G. & BEAVEN, C.M. (2010). Effects of a short-term pre-season training programme on the body composition and anaerobic performance of professional rugby union players. *Journal of Sports Science*, 28(6): 679-686.

ATKINS, S.J. (2006). Performance of the yo-yo intermittent recovery test by elite professional and semi-professional rugby league players. *Journal of Strength and Conditioning Research*, 20(1): 222-225.

AUBERT, A.E., SEPS, B. & BECKER, F. (2003). Heart-rate variability in athletes. *Journal of Sports Medicine*, 33(12): 889-919.

AZIZ, A.R., TEO, E., TAN, B. & THE, K.O. (2003). Sepaktakraw: A descriptive analysis of heart-rate and blood-lactate response and physiological profiles of elite players. *International Journal of Applied Sport Sciences*, 15(1): 1-10.

AZIZ, A.R. & CHUAN, T.E.H. (2004). Correlation between tests of running repeated sprint ability and anaerobic capacity by Wingate cycling in multi-sprint sport athletes. ***International Journal of Applied Sport Sciences***, 16(1): 14-22.

AZIZ, A., NEWTON, M.J. & THE, K.C. (2006) Variations in fitness attributes of players during a competitive season in an Asian professional soccer league: A field base investigation. ***Asian Journal of Exercise & Sport Science***, 3(1): 40-45.

BAECHLE, T.R. & EARLE, R.W. (2000). **Essentials of strength training and Conditioning (2nd ed.)**. Champaign, Illinois: Human Kinetics Books.

BAILLIE, Y., WYON, M. & HEAD, A. (2007). Highland dance: Heart-rate and blood-lactate differences between competition and class. ***International Journal of Sports Physiology and Performance***, 2:371-376.

BAKER, D. (1998). Applying the in-season periodisation of strength and power training to football. ***Journal of Strength and Conditioning Research***, 20(2):18-27.

BANFI, G., DEL FABBRO, M., MAURIS, C., CORSI, M.M. & MELEGATI, G. (2006). Haematological parameters in elite rugby players during a competitive season, ***Clinical and Laboratory Haematology***, 28: 183-188.

BANGSBO, J., MOHR, M. & KRUSTRUP, P. (2006). Physical and metabolic demands of training and match-play in the elite football player. ***Journal of Sport Science***, 24(7): 665-674.

BARBERO-ALVAREZ, J.C., SOTO, V.M., BARBERO-ALVAREZ, V. & GRANDA-VERA, J. (2008). Match analysis and heart-rate of futsal players during competition. ***Journal of Sport Sciences***, 26(1): 63-73.

BARNETT, A. (2006). Using recovery modalities between training sessions in elite athletes. ***Journal of Sports Medicine***, 36(9): 781-796.

BAUMERT, M., BRECHTEL, L., LOCK, J., HERMSDORF, M., WOLFF, R., BAIER, V. & VOSS, A. (2006). Heart-rate variability, blood pressure variability and Baroreflex sensitivity in over trained athletes. ***Clinical Journal of Sports Medicine***, 16: 412-417.

BERKOFF, D.J., CAIRNS, C.B., SANCHEZ, L.D. & MOORMAN, C.T. (2007). Heart-rate variability in elite American track-and-field athletes. ***Journal of Strength and Conditioning Research***, 21(1): 227-231.

BILLAT, L.V. (2001). Interval training for performance: A scientific and empirical practice. Special recommendations for middle-and long-distance running. Part II: Anaerobic interval training. ***Journal of Sports Medicine***, 31(2): 75-90.

BILLAT, V.L., SIRVENT, P., PY, G., KPRALSZTEIN, J.P. & MERCIER, J. (2003). Concept of maximal lactate steady: A bridge between biochemistry, physiology and sport science. ***Journal of Sport Medicine***, 33 (6): 407-426.

BISHOP, D., BURNETT, A., FARROW, D., GABBETT, T. & NEWTON, R. (2006). Sport-science roundtable: Does sport science research influence practice? ***International Journal of Sport Physiology and Performance***, 1:161-168.

BISHOP, P.A., IONES, E. & WOODS, A.K. (2008). Recovery from training: A brief review. ***Journal of Strength and Conditioning Research***, 22(3) : 1015-1024.

BLAIR, J. (1990). **Rugby fitness**. Auckland, N.Z.: SeTo Publishing.

BLOOMFIELD, J., POLMAN, R., O'DONOGHUE, S. & MCNAUGHTON, L. (2007). Effective speed and agility conditioning methodology for random intermittent dynamic type sports. ***Journal of Strength and Conditioning Research***, 21(4): 1093-1100.

BOMPA, T.J. (2006). Total Training for Team Sports. Toronto: Sport Books Publishers.

BOMPA, T.O. & CLARO, F. (2009). **Periodisation in Rugby**. Maidenhead: Meyer & Meyer Sport.

BORRESEN, J. & LAMBERT, M.I. (2008a). Autonomic control of heart-rate during and after exercise: Measurements and implications for monitoring. ***Journal of Sport Medicine***, 36(8): 633-616.

BORRESEN, J. & LAMBERT, M.I. (2008b). Quantifying training load: A Comparison of subjective and objective methods. ***International Journal of Sports Physiology and Performance***, 3: 16-30.

BOURDON, P. (2000). **Physiological Tests for Elite Athletes**. Champaign IL: Human kinetics.

BOUHLEL, B., JOUINI, A., GMADA, N., NEFZIB, A., ABDALLAH, K.B. & TABKA, Z. (2006). Heart-rate and blood-lactate responses during Taekwondo training and competition. ***Journal of Sport Sciences***, 21: 285-290.

BRACEWELL, P.J. (2003). Monitoring meaningful rugby ratings. ***Journal of Sports Sciences***, 21: 611-620.

BRADLEY, P.S., SHELDON, W., WOOSTER, B., OLSEN, P., BOANAS, P. & KRUSTRUP, P. (2009). High-intensity running in English FA premier league soccer matches. ***Journal of Sport Sciences***, 27(2): 159-168.

BREWER, J. & DAVIS, J. (1995). Applied physiology of rugby league. ***Journal of Sport Medicine***, 20(3): 129-135.

BROOKS, J.H.M., FULLER, C.W., KEMP, S.P.T. & REDDIN, D.B. (2005). A prospective study of injuries and training amongst the England 2003 Rugby World Cup squad. . ***British Journal of Sports Medicine***, 39:288-293.

BROOKS, J.H.M., FULLER, C.W., KEMP, S.P.T & REDDIN, D.B. (2008). An assessment of training volume in professional rugby union and its impact on the incidence, severity, and nature of match and training injuries. ***Journal of Sport Sciences***, 26(8):863-873.

BROOKS, J.H.M. & KEMP, S.P.T. (2010). Injury-prevention priorities according to playing position in professional rugby union players. Published document. <http://bjsm.bmj.com/content/early/2010/05/12/bjism.2009.066985.full.html>

BRUGHELLI, M., CRONIN, J., LEVIN, L. & CHAOUACHI, A. (2008). Understanding change of direction ability in sport: A review of resistance training studies. ***Journal of Sports Medicine***, 38(12):1045-1063.

BUFORD, T.W., ROSSI, S.J., SMITH, D.B. & WARREN, A.J. (2007). A comparison of periodisation models during nine weeks with equated volume and intensity for strength. ***Journal of Strength and Conditioning Research***, 21(4): 1245-1250.

BURNLEY, M. & JONES, A.M. (2007). Oxygen uptake kinetics as a determinant of sports performance. ***European Journal of Sport Science***, 7(2):63-79.

CARWYN, J. (1983). **Focus on rugby: An international coaching book**. London, Hutchinson Publishing.

CASTAGNA, C., IMPELLIZZERI, F.M., CHAMARI, K., CARLOMAGNO, D. & RAMPININI, E. (2006). Aerobic fitness and Yo-Yo continuous and intermittent tests performances in soccer players: A correlation study. ***Journal of Strength and Conditioning Research***, 20(2): 320-325.

CASTAGNA, C., ABT, G. & D'OTTAVIO, C. (2007). Physiological aspects of soccer refereeing performance and training. ***Journal of Sports Medicine***, 37(7): 625-646.

CHAOUACHI, A., BRUGHELLI, M., LEVIN, F., BOUDINA, N.B.B, CRONIN, J. & CHAMARI, K. (2009). Anthropometric, physiological and performance characteristics of elite team-handball players. ***Journal of Sport Science***, 27(2): 151-157.

CHATTERJEE, P., BANERJEE, A.K., MAJUMDAR, P. & CHATTERJEE, P. (2005). Oxygen consumption, heart-rate and blood-lactate response. ***International Journal of Applied Sports Sciences***, 17(2): 9-16.

CLARK, N.A., EDWARDS, A.M., MORTON, R.H. & BUTTERLY, R.J. (2008). Season-to-season variations of physiological fitness within a squad of professional male soccer players. ***Journal of Sports Science and Medicine***, 7:157-165.

COFFEY, V.G. & HAWLEY, J.A. (2007). The molecular bases of training adaptation. ***Journal of Sports Science and Medicine***, 37(9):737-763.

CORMACK, S.J., NEWTON, R.U., MCGUIGAN, M.R. & CORMIE, P. (2008). Neuromuscular and endocrine responses of elite players during an Australian rules football season. ***International Journal of Sports Physiology and Performance***, 3:439-453.

COUTTS, A., REABURN, P. & ABT, G. (2003). Heart-rate, blood-lactate concentration and estimated energy expenditure in a semi-professional rugby league team during a match: A case study. ***Journal of Sports Sciences***, 21: 97-103.

COUTTS, A.J., REABURN, P., TERRENCE, T.J. & ROWSELL, G.J. (2007). Monitoring for overreaching in rugby league players. ***European Journal of Applied Physiology***, 99:313-324.

COUTTS, A.J., RAMPININI, E., MARCORÀ, S.M., CASTAGNA, C., IMPELLIZZERI, F.M. (2009). Heart-rate and blood-lactate correlates of perceived exertion during small-sided soccer games. *Journal of Science and Medicine in Sport*, 12: 79-84.

CRAVEN, D.H. (1966). **ABC van Rugby**. Janssorius & Heyns uitgewers.

CRAVEN, D.H. (1970). **Rugbyhandboek**. Kaapstad: Tafelberg Uitgewers.

CRESSWELL, S.L. & EKLUND, R.C. 2006. Changes in athlete burnout over a thirty-week "rugby year". *Journal of Science and Medicine in Sport*, 9:125-134.

CRONIN, J & HANSEN, K.T. (2006). Resisted sprint training for acceleration phase of sprinting. *Journal of Strength and Conditioning Research*, 28(4): 42-51.

CUNNIFFE, B., PROCTOR, W., BAKER, K.S. & DAVIES, B. (2009). An evaluation of the physiological demands of elite rugby union using Global Positioning System tracking software. *Journal of Strength and Conditioning Research*, 23(4): 1195-1203.

DA SILVA, C., D.BLOOMFIELD, J. & MARINS, J.C.B. (2008). A review of stature, body mass and maximal oxygen uptake profiles of U17, U20 and first division players in Brazilian soccer. *Journal of Sports Science and Medicine*, 7: 309-319.

DAVIES, G. & EALES, J. (2003). **The History of the Rugby World Cup**. Sanctuary publishers.

DAVIS, J.A. & BREWER, J. (1993). Applied physiology of female soccer players. *Journal of Sports Medicine*, 16(3): 180-190.

DAVIS, M. & IRELAND, D. (1985). **The Science of Rugby Football**. Great Britain : Butler & Tanner Ltd.

D'ARTIBALE, E., TESSITORE, A. & CAPRANICA, L. (2008). Heart-rate and blood-lactate concentration of male road-race motorcyclists. ***Journal of Sports Sciences***, 26(7): 683-689.

DELLAL, A., WONG, D.P., MOALLA, W. & CHAMARI, K. (2010). Physical and technical activity of soccer players in the French first league with special reference to their playing position. ***International Sports Medicine Journal***, 11(2): 278-290.

DENNIS, S.C. & NOAKES, T.D. (1998). Physiological and metabolic responses to increasing work rates: Relevance for exercise prescription. ***Journal of Sports Sciences***, 16: S77-S84.

DEUTCH, M.U., MAW, G.J., JENKINS, D. & REABURN, P. (1998). Heart-rate, blood-lactate and kinematic data of elite colts (under19) Rugby union players during competition. ***Journal of Sport Sciences***, 16: 561-570.

DEUTCH, M.U., KEARNEY, G.A. & REHRER, N.J. (2007). Time - motion analysis of professional rugby union players during match-play. ***Journal of Sports Sciences***, 25(4): 461-472.

DEUTCH, M. & LLOYD, R. (2008). Effects of order of exercises on performance during a complex training session in rugby players. ***Journal of Sport Sciences***, 26(8): 803-809.

DE VOS, A.S. (1998). ***Research at grass roots: A primer for the caring professions***. Pretoria: J.L. van Schaik Publishers.

DIMKPA, U. (2009). Post-exercise heart-rate recovery: An index of cardiovascular fitness. ***Journal of Exercise Physiology***, 12(1): 10-22.

DOCHERTY, D., WENGER, H.A. & NEARY, P. (1988). Time motion analysis related to the physiological demands of rugby. ***Journal of Human Movement Studies***, 14: 269-277.

DOUTRELOUX, J.P., TEPE, P., DEMONT, M., PASSELERGUE, P. & ARTIGOT, A. (2002). Energy demands of playing positions in rugby union. ***Journal of Science and Sport***, 17(4): 189-197.

DRUST, B., ATKINSON, G. & REILLY, T. (2007). Future perspectives in the evaluation of the physiological demands of soccer. ***Journal of Sports Medicine***, 37(9): 783-805.

DUPONT, G., AKAKPO, K. & BERTHOIN, S. (2004). The effect of in-season, high-intensity interval training in soccer players. ***Journal of Strength and Conditioning Research***, 18(3): 584-589.

DUROCHER, J.J., LEETUN, D.T. & CARTER, J.R. (2008). Sport-specific assessment of lactate threshold and aerobic capacity throughout a collegiate hockey season. ***Applied Physiology, Nutrition & Metabolism***, 33: 1165-1171.

DUTHIE, G., PYNE, D. & HOOPER, S. (2003). Applied physiology and game analysis of rugby union. ***Journal of Sport Medicine***, 33(13): 973-991.

DUTHIE, G.M., PYNE, D.B., ROSS, A.A., LIVINGSTONE, S.G. & HOOPER, S.L. (2006a). The reliability of the ten-meter sprint time using different starting techniques. ***Journal of Strength and Conditioning Research***, 20(2): 246-251.

DUTHIE, G.M., PYNE, D.B., MARSH, D.J. & HOOPER, S.L. (2006b). Sprinting patterns in rugby union players during competition. ***Journal of Strength and Conditioning Research***, 20(11): 208-214.

DUTHIE, G.M. (2006). A framework for the physical development of elite rugby union players. *International Journal of Sports Physiology and Performance*, (1): 1-13.

DWYER, R. (1992). **Winning ways**. London: Pelham.

EATON, C. & GEORGE, K. (2006a). Position specific rehabilitation for rugby union players. Part I: Empirical movement analysis data. *Physical Therapy in Sport*, 7(1): 22-29.

EATON, C. & GEORGE, K. (2006b). Position specific rehabilitation for rugby union players. Part II: Evidence-based examples. *Physical Therapy in Sport*, 7(1): 30-35.

EKBLOM, B. (1986). Applied physiology of soccer. *Journal of Sports Medicine*, 3(1): 50-60.

ELLOUMI, M., OUNIS, O.B., TABKA.Z., VAN PRAAGH, E., MICHAUX, O. & LAC, G. (2008). Psychoendocrine and physical performance responses in male Tunisian rugby players during an international competitive season. *Journal of Aggressive Behaviour*, 34: 623-632.

ELLIOTT.M.C.C.W., WAGNER, P. P. & CHIU, L. (2007). Power athletes and distance training: Physiological and biochemical rationale for change. *Journal of Sports Medicine*, 37(1): 47-57.

ENISELER, N. (2005). Heart-rate and blood-lactate concentrations as predictors of physiological load on elite soccer players during various soccer training activities. *Journal of Strength and Conditioning Research*, 19(4): 799- 804.

EAVES, S. & HUGHES, M. (2003). Patterns of play of international rugby union teams before and after the introduction of professional status. *International Journal of Performance Analysis in Sport*, 3(2): 103-111.

FARROW, D., PYNE, D. & GABBETT, T. (2008), Skill and physiological demands of open and closed training drills in Australian football. ***International Journal of Sports Science and Coaching***, 3(4): 489-499.

FUKUBA, Y., WALSH, M.L., MORTON, R.H., CAMERON, B.J., KENNY, C.T. & BANISTER, E.W. (1999). Effect of endurance training on blood-lactate clearance after maximal exercise. ***Journal of Sports Sciences***, 17: 239-248.

GABBETT, T.J. (2000). Physiological and anthropometric characteristics of amateur rugby league players. ***British Journal of Sports Medicine***, 34(4): 303-307.

GABBETT, T.J. (2002a). Influence of physiological characteristics on selection in a semi-professional first grade rugby league team: A case study. ***Journal of Sports Sciences***, 20: 399-405.

GABBETT, T.J. (2002b). Physiological characteristics of junior and senior rugby league players. ***British Journal of Sports Medicine***, 36: 334-339.

GABBETT, T.J. (2004). Incidence in injury in junior and senior rugby league players. ***Journal of Sports Medicine***, 34 (12): 849-859.

GABBETT, T.J. & DOMROW, D. (2005). Risk factors for injury in sub-elite rugby league players. ***The American Journal of Sports Medicine***, 33(3): 428-434.

GABBETT, T.J. (2005a). Science of rugby league football: A review. ***Journal of Sports Sciences***, 23(9): 961-976.

GABBETT, T.J. (2005b). A comparison of physiological and anthropometric characteristics among playing positions in junior rugby league players. ***British Journal of Sports Medicine***, 39: 675-680.

GABBETT, T.J. (2005c). Changes in physiological and anthropometric characteristics of rugby league players during a competitive season. ***Journal of Strength and Conditioning Research***, 19(2): 400-408.

GABBETT, T.J. (2006). A comparison of physiological and anthropometric characteristics among playing positions in sub-elite rugby league players. ***Journal of Sport Sciences***, 24(12): 1273-1280.

GABBETT, T.J. (2007). Physiological and Anthropometric Characteristics of Elite Women Rugby League Players. ***Journal of Strength and Conditioning Research***, 21(3): 875-881.

GABBETT, T.J. & DOMROW, N. (2007). Relationships between training load, injury, and fitness in sub-elite collision sport athletes. ***Journal of Sports Science***, 25(13): 1507-1519.

GABBETT, T., KELLY, J. & PEZET, T. (2007). Relationship between physical fitness and playing ability in rugby league players. ***Journal of Strength and Conditioning Research***, 21(4): 1126-1133.

GABBETT, T.J. (2008). Influence of fatigue on tackling technique in rugby league players. ***Journal of Strength and Conditioning Research***, 22(2): 625-632.

GABBETT, T. KING, T. & JENKINS, D. (2008). Applied physiology of rugby league. ***Journal of Sports Medicine***, 38(2): 119-138.

GABBETT, T., KELLY, J., RALPH, S. & DRISCOLL, D. (2009a). Physiological and anthropometric characteristics of junior elite and sub-elite rugby league players, with special reference to starters and non-starters. ***Journal of Science and Medicine in Sport***, 12: 215-222.

GABBETT, T., JENKINS, D. & ABERNETHY, B. (2009b). Game-Based training for improving skill and physical fitness in team sport athletes. ***International Journal of Sport Science and Coaching***, 4(2): 273-283.

GAMBLE, P. (2004a). A skill-based conditioning games approach to metabolic conditioning for elite rugby football players. ***Journal of Strength and Conditioning Research***, 18(3): 491-497.

GAMBLE, P. (2004b). Physical preparation for elite-level rugby union football. ***Journal of Strength and Conditioning Research***, 26(4): 10-23.

GAMBLE, P. (2006). Implications and applications of training specificity for coaches and athletes. ***Journal of Strength and Conditioning Research***, 28(3): 54-58.

GARCIA-PALLARÉS, J., GARCIA-FERNÁNDEZ, SÁNCHEZ-MEDINA, L. & IZQUIERDO, M. (2010). Performance changes in world-class kayakers following two different training periodisation models. ***European Journal of Applied Physiology***, 110:99-107.

GARRANDES, F., COLSON, S.S., PENSINI, M. & LEGROS, P. (2005). Neuromuscular fatigue kinetics are sport specific. ***Computer Methods in Biomechanics and Biomedical Engineering***, Supplement 1: 113-114.

GASTIN, P.B. (2001). Energy system interaction and relative contribution during maximal exercise. ***Journal of Sports Medicine***, 31(10): 725-741.

GLAISTER, M. (2005). Multiple sprint work: Physiological responses, mechanism of fatigue and the influence of aerobic fitness. ***Journal of Sport Medicine***, 35(9): 757-777.

GHOSH, A.K. (2008). Heart-rate and blood-lactate responses during execution of some specific strokes in badminton drills. *International Journal of Applied Sports Sciences*, 20(2): 27-36.

GRANT, S.J., OOMMEN,G., MCOLL,G., TAYLOR,J., WATKINS,L., WATT,I. & MCLEAN,D. (2003). The effect of ball carrying method on sprint speed in rugby union football players. *Journal of Sports Science*, 21:1009-1015.

GREIG, M.P., NAUGHTON L.R. & LOVELL, R.J. (2006). Physiological and mechanical responses to soccer-specific intermittent activity and steady state activity. *Research in Sport Medicine*, 14:29-52.

GUÈVEL, A., MAÏSETTI, O., PROU, E., DUBOIS, J.J. & MARINI, J.F.O. (1999). Heart-rate and blood-lactate responses during competitive Olympic boardsailing. *Journal of Sports Sciences*, 17: 135-141.

GUSTAFSSON, H., HOLOMBERG, H. & HASSMÉN, P. (2008). An elite endurance athlete's recovery from underperformance aided by a multidisciplinary sport science support team. *European Journal of Sport Science*, 8(5): 267-276.

HADDAD, H.A., LAURSEN, P.B., AHMAIDI, S. & BUCHHEIT, M. (2009). Nocturnal heart-rate variability following supramaximal intermittent exercise. *International Journal of Sports Physiology and Performance*, 4: 435-447.

HALSON, S.L. & JEUKENDRUP, A.E. (2004). Does overtraining exist? An analysis of overreaching and overtraining research. *Journal of Sports Medicine*, 34 (14): 967-981.

HALSON, S.L. (2008). Nutrition, sleep and recovery. *European Journal of Sport Science*, 8(2): 119-126.

HANEKOM, A., DE RIDDER, H., HARE, E. & MALAN, D.D.J. (2008). Veranderinge ten opsigte van antropometriese en motoriese Komponente vanaf 2000-2001-seisoen by O/19-, O/21-en senior elite-klubrugbyspelers. ***South African Journal for Research in Sport, Physical Education and Recreation***, 30(1): 29-48.

HARISSON, A.J. & BOURKE, G. (2009). *The effect of resisted sprint training on speed and strength performance in male rugby players.* ***Journal of Strength and Conditioning Research***, 23(1): 275-283.

HARTWIG, T.B., NAUGHTON, G. & SEARL, J. (2009). Load, stress, and recovery in adolescent rugby union players during a competitive season. ***Journal of Sport Sciences***, 27(10): 1087-1094.

HASEGAWA, H. (2005). **Optimization of the Exercise Intensity Using Real-Time Heart-rate Telemetry System during a Technical and Tactical Training in Football.** Presentation in the 2nd Congress of The Japanese Society of Science and Football, March 5th-6th, 2005. Tokyo Institute of Technology, Tokyo Japan.

HAZELDINE, R. & MCNAB, T. (1991). **Fit for rugby.** London: The Kingswood press.

HOFF, J. (2005). Training and testing physical capacities for elite soccer players. ***Journal of Sport Sciences***, 23(6): 573-582.

HOFF, J. & HELGERUD, J. (2004). Endurance and strength training for soccer players: Physiological considerations. ***Journal of Sports Medicine***, 34(3): 165-180.

HOLLOWAY, K.M., MEIR, R.A., BROOKS, L.O. & PHILLIPS, C.J. (2008). The triple-120 meter shuttle test: a sport-specific test for assessing anaerobic endurance fitness in rugby league players. ***Journal of Strength and Conditioning Research***, 22(2): 633-639.

HOLWAY, F.E. & GARAVAGLIA, R. (2009). Kinanthropometry of group I players in Buenos Aires, Argentina. ***Journal of Sports Sciences***, 27(11): 1211-1220.

HYLLEGARD, R., MOOD, D.P. & MORROW, J.R. (1996). **Interpreting Research in Sport and Exercise**. Missouri, USA: Mosby publishers.

IAIA, F.M., RAMPININI, E. & BANGSBO, J. (2009). High intensity training in Football. ***International Journal of Sports Physiology and Performance***, 4: 291-306.

ISSURIN, V.B. (2010). New horizons for the methodology and physiology of training periodisation. ***Journal of Sports Medicine***, 40(3):189-206.

JAMES, N., MELLALIEU, S.D. & JONES, M.P. (2005). The development of position-specific performance indicators in professional rugby union. ***Journal of Sports Science***, 23: 63-72.

JARVIS, S., SULLIVAN, L.O., DAVIES, B., WILTSHIRE, H. & BAKER, J.S. (2009). Interrelationship between measured running intensities and agility performance in sub elite rugby union players. ***Research in Sports Medicine***, 17: 217-230.

JEFFREYS, I. (2005). Post game recovery strategies for rugby. ***NSCA's Performance Training Journal***, 6(4): 13-16.

JEUKENDRUP, A. & DIEMEN, A. (1998). Heart-rate monitoring during training and competition in cyclists. ***Journal of Sports Sciences***, 16: 91-99.

JONES, S. & DRUST, B. (2007). Physiological and technical demands of 4v4 and 8v8 games in elite youth soccer players. ***Kinesiology***, 39(2): 150-156.

JOUGLA, A., MICALLEF, J.P. & MOTTET, D. (2009). Effects of active vs passive recovery on repeated rugby-specific exercises. *Journal of Science and Medicine in Sport*, 10(4):1016-1022.

KAMENJU, J.W., WANDERI, M.P. & NTEERE, J.S (2006). Aerobic capacity of Kenyan rugby union players. Published document. www.icce-conference.co.za/docs/presentations/1doc

KAY, B. & GILL, N.D. (2004). Physical demands of elite Rugby League referees, part two: Heart-rate responses and implications for training and fitness testing. *Journal of Science and Medicine in Sport*, 7(2): 165-173.

KAPLAN, K.M., GOODWILLIE, A., STRAUSS, E.J & ROSEN, J.E. (2008). Rugby injuries: A review of concepts and current literature. *Bulletin of the NYU Hospital for Joint Diseases*, 66(2): 86-93.

KELLMANN, M. (2002). **Preventing Underperformance in Athletes**. Champaign, Illinois: Human Kinetics Books.

KELLY, V.G. & COUTTS, A.J. (2007). Planning and monitoring training loads during the competitions phase in team sports. *Journal of Strength and Conditioning Research*, 29(4): 32-37.

KING, D., HUME, P., MILBURN, P. & GUTTENBEIL, D. (2009). Physiological and anthropometrical characteristics of rugby league players. *South African Journal for Research in Sport, Physical Education and Recreation*, 31(2): 49-67.

KING, D., CLARK, T. & KELLMANN (2010). Changes in stress and recovery as a result of participating in a premier rugby league representative competition. *International Journal of Sports Science & Coaching*, 5(2): 223-237.

KIN-ISLER, A. (2006). Time-of-day effects in maximal anaerobic performance and blood-lactate concentrations. *Isokinetics and Exercise Science*, 14: 335-340.

KOVACS, M.S. (2007). Tennis physiology: Training the competitive athlete. *Journal of Sports Medicine*, 37(3): 189-198.

KRAEMER, W.J., FRENCH, D.N., PAXTON, N.J., HAKKINEN, K., VOLEK, J.S., SEBASTIANELLI, W.J., PUTUKIAN, M., NEWTON, R.U., RUBIN, M.R., GOMEZ, A.L., VESCOVI, J.D., RATAMESS, N.A., FLECK, S.J. LYNCH, J.M. & KNUTTGEN, H.G.(2004). Changes in exercise performance and hormonal concentrations over a big ten soccer season in starters and nonstarters. *Journal of Strength and Conditioning Research*, 18(1): 121-128.

KRISTENSEN, G.O., VAN DEN TILLAAR, R. & ETTEMA.G.J.C. (2006). Velocity specificity in early-phase sprint training. *Journal of Strength and Conditioning Research*, 20(4): 833-837.

KRUISTRUP, P. & BANGSBO, J. (2001). Physiological demands of top-class soccer refereeing in relation to physical capacity: effect of intense intermittent exercise training. *Journal of Sports Sciences*, 19: 881-891.

KRUISTRUP, P., HELSEN, W., RANDERS, M.B., CHRISTENSEN, J.F., MACDONALD, C., REBELO, A.N. & BANGSBO, J. (2009). Activity profile and physical demands of football referees and assistant referees in international games. *Journal of Sports Sciences*, 27(11): 1167-1176.

LAKOMY, J. & HAYDON, D.T. (2004). The effects of enforced, rapid deceleration on performance in multiple sprint test. *Journal of Strength and Conditioning Research*, 18(3): 579-583.

LAMBERTS, R.P., LEMMINK, A.P.M., DURANDT, J.J. & LAMBERT, M.L. (2004). Variation in heart-rate during sub maximal exercise: Implications for monitoring training. ***Journal of Strength and Conditioning Research***, 18(3): 641-645.

LAMBERT, M.I., MBAMBO, Z.H. & ST CLAIR GIBSON, A. (1998). Heart-rate during training and competition for long distance running. ***Journal of Sport Sciences***, 16: 85-90.

LARK, S.D. & MCCARTHY, P.W. (2009). The effects of a single game of rugby on active cervical range of motion. ***Journal of Sports Science***, 27(5): 491-497.

LAURENT, C.M. & GREEN, J.M. (2009). Multiple models can concurrently explain fatigue during human performance. ***International Journal of Exercise Science***, 2(4): 280-293.

LEE, A.J., GARRAWAY, W.M. & ARNEIL, D.W. (2001). Influence of preseason training, fitness, and existing injury on subsequent rugby injury. ***British Journal of Sports Medicine***, 35:412-417.

LEGER, L. & THIVIERGE, M. (1988). Heart-rate monitors: validity, stability and functionality. ***Journal of Physical Sport Medicine***, 16: 143-151.

LITTLE, T. & WILLIAMS, A.G. (2007). Effects of sprint duration and exercise: Rest ratio on repeated sprint performances and physiological responses in professional soccer players. ***Journal of Strength and Conditioning Research***, 21(2) : 646-648.

LUGER, D. & POOK, P. (2004). **Complete Conditioning for Rugby**. Champaign, Illinois: Human Kinetics Books.

LEMYRE, P., N.ROBERTS, G.C. & STRAY-GUNDERSEN, J. (2007). Motivation, overtraining, and burnout: Can self-determined motivation predict overtraining and burnout in elite athletes? *European Journal of Sport Science*, 7(2): 115-126.

LYONS, M., AL-NAKEEB, Y. & NEVILL, A. (2006). Performance of soccer passing skills under moderate and high-intensity localized muscle fatigue. *Journal of Strength and Conditioning Research*, 20(1): 197-202.

MAIN, L. & GROVE, J, R. (2009). A multi-component assessment model for monitoring training distress among athletes. *European Journal of Sport Science*, 9(4): 195-202.

MAKARUK, B., MAKARUK, H., SACEWICZ, T., MAKARUK, T., STANISLAW, K. & DLUGOLECKA, B. (2009). Validity and reliability of measurement of kinematic parameters in a running speed test. *Polish Journal of Sport & Tourism*, 16: 85-92.

MANOLOPOULOS, E., PAPADOPOULOS, C. & KELLIS, E. (2006). Effects of combined strength and kick coordination training on soccer kick biomechanics in amateur players. *Scandinavian Journal of Medicine & Science in Sports*, 16:102-110.

MARSHALL, J. (2005). In-season periodisation with youth rugby players. *Journal of Strength and Conditioning Research*, 27(5): 10-19.

MASHIKO, T., UMEDA, T., NAKAJI, S. & SUGAWARA, K. (2004a). Effects of exercise on the physical condition of college rugby players during summer training camp. *British Journal of Sports Medicine*, 38: 186-190.

MASHIKO, T., UMEDA, T., NAKAJI, S. & SUGAWARA, K. (2004b). Position related analysis of the appearance of and relationship between post-match physical and mental fatigue in university rugby football players. *British Journal of Sports Medicine*, 38: 617-621

MASO, F., CAZORLA, G. GODEMET, M., LAC, G. & ROBERT, A. (2002). Physiological features of rugby players of a French team. ***Science and Sports***, 17(6): 297-301.

MAUD, P.J. (1983). Physiological and anthropometric parameters that describe a rugby union match. ***British Journal of Sports Medicine***, 17: 16-23.

MAUD, P.J. & SHULTZ, B.B. (1984). The US national rugby team: A physiological and anthropometric assessment. ***Physician and Sport Medicine***, 12(9): 86-94.

MCLEAN, D.A. (1992). Analysis of the physical demands of international rugby union. ***Journal of Sports Sciences***, 10:285-296.

MCLEAN, S.R., NORRIS, S.R. & SMITH, D.J. (2004). Comparison of the Lactate Pro and the Y5I 1500 sport blood-lactate analyzers. ***International Journal of Applied Sport Sciences***, 16(2): 22-30.

MCMILLAN, K., HELGERUD, J., GARNT, S.J., NEWELL, J., WILSON, J., MACDONALD, R. & HOFF, J. (2005). Lactate threshold responses to a season of professional British youth soccer. ***British Journal of Sports Medicine***, 39: 432-436.

MEEUSEN, R., DUCLOS, M., GLEESON, M., RIETJENS, G., STEINACKERS, J. & URHAUSEN, A. (2006a). Prevention, diagnosis and treatment of the Overtraining syndrome. ***European Journal of Sport Science***, 6(1):1-14.

MEEUSEN, R., DUCLOS, M., GLEESON, M., RIETJENS, G., STEINACKER, J. & URHAUSEN, A. (2006b). The overtraining syndrome: Facts & fiction. ***European Journal of Sport Science***, 6(4): 263.

MEEUSEN, R., WATSON, P., HASEGAWA, H., ROELANDS, B. & PIACENTINI, M.F. (2007). Brain neurotransmitters in fatigue and overtraining. ***Applied Journal of Physiology and Nutrition Metabolism***, 32: 857-864.

MEIR, R., DIESEL, W. & ARCHER, E. (2007). Developing a prehabilitation program in a collision sport. A model developed within English Premiership Rugby Union Football. ***Journal of Strength and Conditioning Research***, 29(3): 50-62.

MELLALIEU, S. (2008). Science and rugby union. ***Journal of Sport Sciences***, 26(8):791-794.

MENCHINELLI, C., MORANDINI, C. & DE ANGELIS, M. (1992). A functional model of rugby: determination of the characteristics of sports performance [abstract]. ***Journal of Sports Sciences***, 10: 196-197.

METAXAS, T.I., KOUTLIANOS, N.A., KOUIDI, E.J. & DELIGIANNIS, A.P. (2005). Comparative study of field and laboratory tests for the evaluation of aerobic capacity in soccer players. ***Journal of Strength and Conditioning Research***, 19(1): 79-84.

MOHR, M., KRUSTRUP, P. & BANGSBO, J. (2003). Match performance of high-standard soccer players with special reference to development of fatigue. ***Journal of Sport Science***, 21:519-528.

MOHR, M., KRUSTRUP, P. & BANGSBO, K. (2005). Fatigue in soccer: A brief review. ***Journal of Sport Science***, 23(6): 593-599.

MONTGOMERY, P.G., PYNE, D.B. & MINAHAN, C.L. (2010). The physical and physiological demands of basketball training and competition. ***International Journal of Sports Physiology and Performance***, 5: 75-86.

MOORE, C.A. & FRY, A.C. (2007). Non functional overreaching during off-season training for skill position players in collegiate American football. ***Journal of Strength and Conditioning Research***, 21(3):793-800.

MORTON, A.R. (1978). Applying physiological principles to rugby training. ***Sport Coach***, 2: 4-9.

NEDERHOF, E., LEMMINK, K.A.M.P., VISSCHER, C.MEEUSEN, R & MULDER, T. (2006). Psychomotor speed: Possibly a new marker for overtraining syndrome. ***Journal of Sport Medicine***, 36(10):817-828.

NICHOLAS, C.W. (1997). Anthropometric and physiological characteristics of rugby union football players. ***Journal of Sports Medicine***, 23(6): 375-396.

NICHOLLS, A.R., JONES, C.R., POLMAN, R.C.J. & BOKOLES, E. (2009). Acute sport-related stressors, coping, and emotion among professional rugby union players during training and matches. ***Scandinavian Journal of Medicine and Science in Sports***, 19: 113-120.

NOAKES, T.D. & DU PLESSIS, M. (1996). **Rugby without risk: A practical guide to the prevention and treatment of rugby injuries**. Pretoria: Van Schaik.

NOAKES, T.D. & DURANDT, J.J. (2000). Physiological requirements of cricket. ***Journal of Sport Sciences***, 18: 919-929.

O'CONNOR, D. (2004). Blood-lactate concentrations measured during competitive games throughout a professional rugby league season [abstract]. ***Journal of Sport Sciences***, 22: 556-557.

OSTOJIC, S.M. (2000). Physical and physiological characteristics of elite Serbian soccer players. ***Physical Education and Sport***, 1(7): 23-29.

PETTITT, R.W., PETTITT, C.D., CABRERA, C.A. & MURRAY, S.R. (2007). A theoretical method of using heart-rate to estimate energy expenditure during exercise. ***International Journal of Sport Science and Coaching***, 2(3): 319-327.

PILIANIDIS, T., MARIGLI, H., DOUDA, H., MANTZOURANIS, N., SMILIOS, I. & TOKMAKADIS. (2007). Reliability and validity of a modified field test for the evaluation of aerobic performance. *Kinesiology*, 39(2): 117-123.

PINASCO, A & CARSON, J. (2005). Preseason conditioning for college soccer. *Journal of Strength and Conditioning Research*, 27(5): 56-62.

POLMAN, R. & HOULAHAN, K. (2004). A cumulative stress and training continuum model: A multidisciplinary approach to unexplained underperformance syndrome. *Research in Sports Medicine*, 12:301-316.

POSTHUMUS, M. (2009). Physical conditioning for rugby-An evidence based literature review. Published document. www.boksmart.co.za

PHILLIPS, L.H., STANDEN, P.J. & BATT, M.E. (1998). Effects of seasonal change in rugby league on incidence of injury. *British Journal of Sports Medicine*, 32:144-148.

PRICE, M. & HALABI, K. (2005). The effects of work – rest duration on intermittent exercise and subsequent performance. *Journal of Sport Sciences*, 23(8): 835-842.

PRICE, M. & MOSS, P. (2007). The effects of work: rest duration on physiological and perceptual responses during intermittent exercise and performance. *Journal of Sport Sciences*, 25(14): 1613-1621.

QUARRIE, K.L., HANDCOCK, P., TOOMEY, M. & WALLER, A.E. (1996). The New Zealand rugby injury and performance project. IV. Anthropometric and physical performance comparisons between positional categories of senior A rugby players. *British Journal of Sports Medicine*, 30:53-56.

QUARRIE, K.L., ALSOP, J.C. WALLER, A.E., BIRD, Y.N., MARSHALL, S.W. & CHALMERS, D.J. (2001). The New Zealand rugby injury and performance project. VI. A

prospective cohort study of risk factors for injury in rugby union football. ***British Journal of Sports Medicine***, 35:157-166.

QUARRIE, K.L. & HOPKINS, W.G. (2007). Changes in player characteristics and match activities in Bledisloe Cup rugby union from 1972 to 2004. ***Journal of Sports Sciences***, 25(8): 895- 903.

RAHNAMA, N., REILLY, T., LEES, A. & SMITH, P.G. (2003). Muscle fatigue induced by exercise simulating the work rate of competitive soccer. ***Journal of Sport Science***, 21:933-942.

RAMPININI, E., IMPELLIZZER, F. M., CASTAGNA, C., ABT, G., CHAMARI, K., SASSI, A. & MARCORA, M. (2007). Factors influencing physiological responses to small-sided soccer games. ***Journal of Sports Sciences***, 25(6): 659-666.

REILLY, T. (1997a). The physiology of rugby union football. ***Biology of Sport***, 14(2): 83-101.

REILLY, T. (1997b). Energetics of high intensity exercise (soccer) with particular reference to fatigue. ***Journal of Sports Sciences***, 15: 257-263.

REILLY, T. (2005). An ergonomics model of the soccer training process. ***Journal of Sports Sciences***, 23(6): 561-572.

ROBERTS, S.P., TREWARTHA, G., HIGGITT, R.J., EL-ABD, J. & STOKES, K.A. (2008). The physical demands of elite English rugby union. ***Journal of Sport Sciences***, 26(8): 825-833.

ROBERTS, S.P., STOKES, K.A., WESTON, L. & TREWARTHA, G. (2010). The Bath University shuttle test (BURST): A pilot study. ***International Journal of Sports Physiology and Performance***, 5:64-74.

ROZENEK, R., FUNATO, K., KUBO, J., HOSHIKAWA, M. & MATSUO, A. (2007). Physiological responses to interval training sessions at velocities associated with VO₂ max. ***Journal of Strength and Conditioning Research***, 2(1):188-192.

ROWSELL, G.J., COUTTS, A.J., REABURN, P. & HILL-HAAS, S. (2009). Effects of cold-water immersion on physical performance between successive matches in high-performance junior male soccer players. ***Journal of Sport Science***, 27(6): 565-573.

SHEPPARD, J.M. & YOUNG, W.B. (2006). Agility literature review: Classifications, training and testing. ***Journal of Sports Sciences***, 24(9): 919-932.

SCOTT, A.C., ROE, R., COATS, A.J.S. & PIEPOLI, M.F. (2003). Aerobic exercise physiology in a professional rugby union team. ***International Journal of Cardiology***, 87:173-177.

SHESKIN, D.J., (2000). **Parametric and non parametric statistical procedures**, (3rd ed.). Chapman & Hall: CRC Press.

SILVESTRE, R., KRAEMER, W.J., WEST, C., JUDELSON, D.A., SPIERING, B.A., VINGREN, K.L., HATFIELD, D.L., ANDERSON, J.M. & MARESH, C.M. (2006). Body composition and physical performance during a national collegiate athletic association division I men's soccer season. ***Journal of Strength and Conditioning Research***, 20(4): 962-970.

SIROTIC, A.C., COUTTS, A.J., KNOWLES, H. & CATTERICK, C. (2009). A comparison of match demands between elite and semi-elite rugby league competition. ***Journal of Sports Sciences***, 27(3): 203-211.

SLIWOWSKI, R., JOZWIAK, J., PIETRZAK, M., WIECZOREK, A. & WIECZOREK, J. (2007). Aerobic performance of young football players in the preparatory period. ***Studies in Physical Culture and Tourism***, 14:293-297.

SMITH, H. (1998). Applied physiology of water polo. *Journal of Sports Medicine*, 26(5): 317-334.

SMITH, D.J. (2003). A framework for understanding the training process leading to elite performance. *Journal of Sports Medicine*, 33(15): 1103-1126.

SPENCER, M., BISHOP, D., DAWSON, B. & GOODMAN, C. (2005). Physiological and metabolic responses of repeated-sprint activities: Specific to field-based sports. *Journal of Sports Medicine*, 35(12): 1025-1044.

SPINKS, C.D., MURPHY, A.J., SPINKS. & LOCKIE, R.G. (2007). The effects of resisted sprint training on acceleration performance and kinematics in soccer, rugby union and Australian football players. *Journal of Strength and Conditioning Research*, 21(1): 77-85.

SPORIS, G., MILANOVIC, JUKIC, I., OMRČEN, D. & MOLINUEVO, J.V. (2010). The effect of agility training on athletic power performance. *Kinesiology*, 42: 65-72.

STAGNO, K.M., THATCHER, R. & VAN SOMEREN, K.A. (2007). A modified TRIMP to quantify the in-season training load of team sport players. *Journal of Sports Sciences*, 25(6):629-634.

STOLEN, T., CHAMARI, K., CASTANGA, C. & WISLOFF, U. (2005). Physiology of Soccer: An update. *Journal of Sports Medicine*, 35 (6): 501-536.

STONE, K.J. & OLIVER, J.L. (2009). The effect of 45 minutes of soccer-specific exercise on the performance of soccer skills. *International Journal of Sports Physiology and Performance*, 4:163-175.

STONE, N.M. & KILDING, A.E. (2009). Aerobic conditioning for team sport athletes. ***Journal of Sports Medicine***, 39(8): 615-642.

SWART, J. & JENNINGS, C.L. (2004). Use of blood-lactate concentration as a marker of training status. ***South African Journal of Sports Medicine***, 16(2):1-5.

SVENSSON, M. & DRUST, B. (2005). Testing soccer players. ***Journal of Sports Sciences***, 23(6): 601-618.

TAKARADA, Y. (2003). Evaluation of muscle damage after a rugby match with special reference to tackle plays. ***British Journal of Sports Medicine***, 37: 416-419.

TERBIZAN, D.J., DOLEZAL, B.A. & ALBANO, C. (2002). Validity of seven commercially available heart-rate monitors. ***Measurement in Physical Education and Exercise Science***, 6(4): 243-247.

TESSITORE, A., MEEUSEN, R., TIBERI, M., CORTIS, C., PAGANO, R. & CAPRANICA, L. (2005). Aerobic and anaerobic profile, heart-rate and match analysis in older soccer players. ***Ergonomics***, 48(11-14): 1365-1377.

TESSITORE, A., TIBERI, M., CORTIS, C., RAPISARDA, E., MEEUSEN, R. & CAPRANICA, L. (2006). Aerobic-anaerobic profiles, heart-rate and match analysis in old basketball players. ***Gerontology*** 52: 214-222.

TESSITORE, A., MEEUSEN, R., CORTIS, C. & CAPRANICAI, L. (2007). Effects of different recovery interventions on anaerobic performance following preseason soccer training. ***Journal of Strength and Conditioning Research***, 21(3): 745-750.

THOMAS, J.R. & NELSON, J.K. (1996). ***Research in Physical Activity***, (3rd ed.). Champaign, Illinois: Human Kinetics Books.

THOMAS, J.R. & NELSON, J.K. (2001). **Research in Physical Activity**, (4th ed.). Champaign, Illinois: Human Kinetics Books.

THOMAS, J.R. & NELSON, J.K. (2005). **Research in Physical Activity**, (5th ed.). Champaign, Illinois: Human Kinetics Books.

TOMLIN, D.L. & WENGER, H, A. (2001). The relationship between aerobic fitness and recovery from high intensity intermittent exercise. **Journal of Sports Medicine**, 31(1) : 1-11.

THOMSON, K., WATT, A. & LIUKKONEN, D. (2009). Differences in ball sports athletes speed discrimination skills before and after exercise induced fatigue. **Journal of Sport Science and Medicine**, 8:259-264.

THOMPSON, D., NICHOLAS, C.W. & WILLIAMS, C. (1999). Muscular soreness following prolonged intermittent high intensity shuttle running. **Journal of Sport Sciences**, 17: 387-395.

THORLUND, J.B., MICHALS, L.B. & AAGAARD, M.P. (2008). Acute fatigue-induced changes in muscle mechanical properties and neuromuscular activity in elite handball players following a handball match. **Scandinavian Journal of Medicine and Science in Sports**, 18:462-472.

TINAZCIA, C. & ACIKADA, C. (2009). Reproducibility and validity of Hacettepe intermittent jumping test. **Isokinetics and Exercise**, 17: 93-99.

TONG, R.J., BELL, W.BALL, G. & WINTER, E.M. (2001). Reliability of power output measurements during repeated treadmill sprinting in rugby players. **Journal of Sports Sciences**, 19: 289-297.

TREWARTHA, G., CASANOVA, R. & WILSON, C. (2008). A kinematic analysis of rugby lineout throwing. *Journal of Sport Science*, 26(8): 845-854.

UUSITALO, A. (2006). A comment on: Prevention, diagnosis and treatment of the overtraining syndrome. *European Journal of Sport Science*, 6(4): 261-262.

VAN GENT, M.M. & SPAMER, E.J. (2005). Comparisons of positional groups in terms of anthropometric, rugby- specific skills, physical and motor components among U13, U 16,U18 and U 19 elite rugby players. *Kinesiology*, 37: 50-63.

VEALE, J.P. & PEARCE, A.J. (2009). Physiological responses of elite junior Australian rules footballers during match play. *Journal of Sports Sciences and Medicine*, 8: 314-319.

VENTER, R.E., POTGIETER, J.R. & BARNARD, J.G. (2010). The use of recovery modalities by elite South African team athletes. *South African Journal for Research in Sport, Physical Education and Recreation*, 32(1):133-145.

VERRALL, G.M., SLAVOTINEK, J.P. & BARNES, P.G. (2005). The effect of sports specific training on reducing Australian Rules football players the incidence of hamstring injuries in professional. *British Journal of Sports Medicine*, 39: 363-368.

VILJOEN, W., SAUNDERS, C.J., HECHTER, G.D., AGINSKY, K.D. & MILLSON, H.B. (2009). Training volume and injury incidence in a professional rugby union team. *South African Journal of Sports Medicine*, 21(3): 97-101.

VUORI, I. (1998). Experiences of heart-rate monitoring in observational and intervention studies. *Journal of Sport Sciences*, 16: 25-30.

VURAL, F., NALCAKAN, G.R., & ÖZKOL, M.Z. (2009). Physical and physiological status in American football players in Turkiye. **Serbian Journal of Sports Sciences**, 3(1-4): 9-17.

WALSH, M., YOUNG, B., HILL, B., KITTREDGE, T. & HORN, T. (2007). The effect of ball-carrying technique and experience on sprinting in rugby union. **Journal of Sport Sciences**, 25(2): 185-192.

WARRINGTON, G., RYAN, C., MURRAY, F., DUFFY, P. & KIRWAN, J.P. (2001). Physiological and metabolic characteristics of elite tug of war athletes. **British Journal of Sports Medicine**, 35: 396-401.

WEERAPONG, P., HUME, P.A. & KOLTZ, G.S. (2005). The mechanisms of massage and effects on performance, muscle recovery and injury prevention. **Journal of Sports Medicine**, 35 (3): 235-256.

WHALEY, M.H. (Ed), (2005). **ACSM'S Guidelines for Exercise Testing and Prescription (7th ed.)** Maryland: Lippencott Williams and Wilkins.

WHEELER, K. & SAYERS, M. (2009). Contact skills predicting tackle-breaks in rugby union. **International Journal of Sports Science & Coaching**, 4(4): 535-544.

WHITEHEAD, N. & COOK, M. (1994). **Soccer training: Games, drills and fitness practices 4th Ed.** London: A&C Black Publishers.

WILCOCK, I.M., CRONIN, J.B. & HING, W.A. (2006). Physiological response to water immersion: A method for sport recovery? **Journal of Sports Medicine**, 36(9): 747-765.

WILLIAMS, J., HUGHES, M. & O'DONOGHUE, P. (2005). The effect of rule changes on match and ball in play time in rugby union. **International Journal of Performance Analysis in Sport**, 5(3):1-11.

WILLIAMS, K. & OWEN, A. (2007). The impact of player numbers on the physiological responses to small sided games. *Journal of Sports Science and Medicine*, Suppl.6 (10): 100.

YOUNG, W., RUSSELL, A., BURGE, P., CLARKE, A. CORMACK, S. & STEWART, G. (2008). The use of sprint tests for assessment of speed qualities of elite Australian rule footballers. *International Journal of Sports Physiology and Performance*, 3:199-206.

ZATSIORSKY, V.M. (1995). **Science and Practice of Strength Training**. Champaign, Illinois: Human Kinetics Books.

ZEMKOVÁ, E. & HAMAR, D. (2009). The effects of soccer match induced fatigue on neuromuscular performance. *Kinesiology*, 41(2): 195-202.