The use of heart rates and graded maximal test values to determine rugby union game intensities

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FOREWORD

I would like to express my sincere appreciation to the following people:

To my heavenly Father, thank You for all my talents and opportunities. Thank You so much for all Your grace and unconditional love! May You be glorified in everything I do!

To my supervisor, Ben Coetzee. Thank you for your guidance during this study and in my daily life. I sincerely appreciate all your dedication, hard work and long hours.

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"Trust in the Lord with all your heart and lean not on your own understanding; in all ways acknowledge him, and he will make your paths straight"

Proverbs 3:5-6

DECLARATION

The co-author of the two articles, which form part of this dissertation, Dr. Ben Coetzee (Supervisor), hereby gives permission to the candidate, Ms. Martinique Sparks to include the two articles as part of a Masters dissertation. The contribution (advisory and supportive) of the co-author was within reasonable limits, thereby enabling the candidate to submit this dissertation for examination purposes. This dissertation, therefore, serves as partial fulfillment of the requirements for the Magister Scientiae degree in Sport Science within the School for Biokinetics, Recreation and Sport Science in the Faculty of Health Sciences at the North-West University (Potchefstroom Campus).

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Dr. Ben Coetzee
Supervisor and co-author

SUMMARY

In order for sport scientists and conditioning coaches to construct sport and position specific training regimens for players, they need to understand the physiological demands different playing positions face during rugby union matches. Despite the inaccuracy of time-motion, heart rate and blood lactate analyses, no researchers have to date attempted to determine the demands of tertiary institution rugby union games by using heart rate and graded maximal test values. It is against this background, that the purposes of this study were firstly, to determine the intensities of tertiary institution rugby union games, using heart rates and graded maximal test values, and secondly, to determine the positional differences in tertiary institution rugby game intensities, using heart rates and graded maximal test values.

In the weeks between three rugby matches, ten forwards and eleven backs, who were selected from the first and second teams of the North-West University (Potchefstroom Campus, South Africa) performed a standard incremental maximal oxygen uptake ($\dot{V}O_{2max}$) test to the point of exhaustion. The test was used to determine two ventilatory threshold points by means of which the low, moderate and high-intensity heart rate zones were identified for each of the players. These heart rate zones were used to determine the amount of time that each player spent in the different intensity zones during matches, whilst heart rate telemetry data was used.

Significant differences ($p < 0.05$) were found between the amount of time each player spent in the low and high-intensity zones (23.2% vs. 37.4%) during the second halves, between the low and moderate (22.8% vs. 33.6%) as well as between the low and high-intensity zones (22.8% vs. 43.6%) for the matches overall. When the independent t-test values were calculated, the study revealed that forwards spent significantly more time in the high-intensity zone compared to the backs (54.6% vs. 32.7%), whereas the backs spent significantly more time in the low-intensity zone during the match compared to the forwards (34.2% vs. 11.3%). Results also indicated that the duration of different intensity bouts were 29 sec for the low, 29 sec for the moderate and 1 min:17 sec for the high-intensity bouts, respectively.

The results of this study showed that the combined use of heart rate and graded maximal test values enabled the researcher to determine the intensities of tertiary institution rugby union games as well as to investigate the significant differences between the game intensities of backs and forwards. The conclusion that can therefore be drawn from the results of this study are that in-game and graded maximal test heart rates as well as other respiratory-related variables will enable sport scientists and other sport-related professionals to draw more valid and accurate conclusions with regard to the demands of rugby union play. It also showed that players, and especially forwards, spent significantly more time in the high-intensity zone than was previously reported.

OPSOMMING

Om dit vir sportwetenskaplikes en kondisioneringsafrigters moontlik te maak om sport- en posisiespesifieke oefenprogramme vir spelers saam te stel, moet hulle die fisiologiese vereistes wat verskillende posisies tydens rugby-uniewedstryde ervaar, verstaan. Ten spyte van die onakkuraatheid van tyd-bewegings-, harttempo- en bloedlaktaatanalises, het geen navorsers, tot dusver, ’n poging aangewend om die vereistes van tersiêre instelling rugby-uniewedstryde te bepaal deur gebruik te maak van harttempo- en inkrementele maksimale toetswaardes nie. Dit is teen hierdie agtergrond dat die doelstellings van hierdie studie ten eerste was om die intensiteite van tersiêre instelling rugby-uniewedstryde te bepaal deur gebruik te maak van harttempo’s en inkrementele maksimale toetswaardes en tweedens, om te bepaal wat die posisionele verskille in tersiêre instelling rugbywedstryd-intensiteite is, deur gebruik te maak van harttempo’s en inkrementele maksimale toetswaardes.

In die weke tussen drie rugbywedstryde het tien voorspelers en elf agterspelers wat uit die eerste en tweede spanne van die Noordwes-Universiteit (Potchefstroomkampus, Suid Afrika) geselekteer is, ’n standaard inkrementele maksimale suurstofopname- ($\dot{V}O_{2maks}$) toets tot by die punt van uitputting uitgevoer. Die toets is gebruik om twee ventilatoriese drempelpunte te bepaal waarvolgens die lae, matige en hoë-intensiteit harttempo-sones vir elk van die spelers geïdentifiseer is. Hierdie harttempo-sones is gebruik om die hoeveelheid tyd wat elke speler in die verskillende intensiteitsones gedurende wedstryde deurgebring het, te bepaal, deur gebruik te maak van harttempo telemetrie-data.

Betekenisvolle verskille ($p < 0.05$) is gevind tussen die hoeveelheid tyd wat elke speler bestee het in die lae en hoë-intensiteitsones (23.2% vs. 37.4%) tydens die tweede helftes, tussen die lae en matige (22.8% vs. 33.6%) sowel as tussen die lae en hoë-intensiteitsones (22.8% vs. 43.6%) tydens die wedstryde in geheel. Met berekening van die onafhanklike t-

toetswaardes het die studie onthul dat voorspelers betekenisvol meer tyd in die hoë-intensiteitsone deurgebring het vergeleke met die agterspelers (54.6% vs. 32.7%), daarenteen het die agterspelers weer betekenisvol meer tyd in die lae-intensiteitsone deurgebring vergeleke met die voorspelers (34.2% vs. 11.3%). Resultate het ook aangedui dat die duur van verskillende intensiteitsbeurte soos volg was: 29 sek vir die lae, 29 sek vir die matige en 1 min:17 sek vir die hoë-intensiteitbeurte, onderskeidelik.

Die resultate van hierdie studie het daarop gedui dat die gekombineerde gebruik van harttempo- en inkrementele maksimale toetswaardes die navorser in staat gestel het om die intensiteite van tersiêre instelling rugby-uniewedstryde te bepaal asook om die betekenisvolle verskille tussen die wedstrydintensiteite van agter- en voorspelers te ondersoek. Die gevolgtrekking wat dus hieruit gemaak kan word, is dat in-wedstryd en inkrementele maksimale toets harttempo's sowel as ander respiratories verwante veranderlikes, sportwetenskaplikes en ander sportverwante professies in staat sal stel om geldiger en akkurater gevolgtrekkings te maak ten opsigte van die vereistes van rugby-uniespel. Dit wys ook daarop dat spelers, veral voorspelers, betekenisvol meer tyd in die hoë-intensiteitsone deurgebring as wat voorheen gerapporteer is.

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LIST OF ABBREVIATIONS

bpm	beats per minute
HR_{avg}	average heart rate
HR_{max}	maximum heart rate
h	hour
IRB	International Rugby Board
$km \cdot h^{-1}$	kilometers per hour
m	meter
m/sec	meter per second
$ml \cdot kg^{-1} \cdot min^{-1}$	millilitre per kilogram per minute
mM/L	millimol per litre
min	minute
n	number of subjects
RCP	respiratory compensation point
RER	respiratory exchange rate
RER_{max}	maximum respiratory exchange rate
s	seconds
$\dot{V}CO_2$	carbon dioxide production
$\dot{V}_E$	minute ventilation
$\dot{V}O_2$	oxygen uptake
$\dot{V}O_{2max}$	maximum oxygen uptake
VT_1	ventilatory threshold

CHAPTER 1

1 PROBLEM STATEMENT AND PURPOSES OF THE STUDY

1. PROBLEM STATEMENT

The demands of rugby union match play are such that players need to exhibit above-average fitness and high skill levels (Scott *et al.*, 2003:173). Coaches and sport scientists will, however, only be able to condition players specifically for the demands of the game if they are aware of the amount of work players need to perform at certain intensities (Luger & Pook, 2004:2). Some of the methods used in recent years for determining the amount of work and work intensities of rugby union games are time-motion analyses (Roberts *et al.,* 2008; Deutch *et al.*, 2007; Duthie *et al.*, 2005; Deutch *et al.*, 1998; McLean, 1992), heart rate recording and analyses (Deutsch *et al.*, 1998) as well as blood lactate monitoring (Deutsch *et al.*, 1998; McLean, 1992). In view of the last-mentioned scenario, the subsequent section will deal with the research that has investigated the application of different methods for determining the demands of various activities.

Duthie *et al.* (2005:523) made use of time-motion analyses to gather information regarding the movement patterns of rugby players and to quantify the demands of a rugby game. The frequency, mean duration, total time spent during activities and distance covered during a game were then used for determining which energy systems contributed most to the different activities performed (Duthie *et al.,* 2005:525). In this regard Duthie *et al.* (2005:530) indicated that Super 12 rugby union games are characterised by relatively brief periods of play which are performed at a high intensity and are interspersed with brief periods (less than 20s) of recovery. Duthie *et al.* (2003:984) reported that 85% of game time was spent in low and moderate activities and 15% in high-intensity activities when u/19 international, elite club and Super 12 rugby games were analysed. Tackles, acceleration from a static position, rucking, mauling, line-out jumping and breaking through tackles are examples of the types of activities that are performed by rugby players during high-intensity periods (Luger & Pook, 2004:4; Duthie *et al.,* 2003:984). Research shows that the energy for performing the brief, intense activities is primarily derived from the anaerobic glycolytic energy system, especially for the forwards (Deutch *et al.,* 2007:471). Deutsch *et al.* (2007:471) also concluded that the brief, high-intensity periods of play are alternated by longer periods of play which are interspersed with brief periods of recovery. Longer, lower intensity activities will usually consist of standing, walking, striding and jogging as determined by time-motion analysis (Deutsch *et al.,* 2007:463; Duthie *et al.,* 2005:525). In their study Deutsch *et al.* (2007:467; 1998:565) found that forwards spend more time being engaged in high-intensity work than backs, because of their greater involvement in rucking, mauling and scrummaging. Consequently inside and outside backs spent more time in moderate and low intensity activities than the forwards (Deutsch *et al.,* 1998:565). With reference to this statement, Duthie *et al.* (2005:529) concluded that the backs (especially the outside backs) had longer periods of rest compared to the forwards.

The validity of time-motion analyses for determining the demands of a rugby union game has, however, been questioned (Deutsch *et al.,* 2007:469). During time-motion analyses, movement patterns are simplified by dividing it into categories, while actual play involves a combination of dynamic tasks, skills and tactics (Duthie *et al.,* 2003:983). Time-motion analyses' results may therefore not reflect the actual demands of a specific game due to measurement errors (Duthie *et al.,* 2003:983). In view of this, researchers have proposed the measurement and use of heart rate and oxygen consumption to quantify exercise intensities (Hills *et al.,* 1998). The development of wireless heart rate monitors and the use of such apparatus to measure, monitor and store the heart rates of players during a game have made this one of the most popular methods for determining game intensities and heart rate changes (Achten & Jeukendrup, 2003:525). Burke (1998:19) has also compiled heart rate guidelines for determining the intensities of certain activities, as well as the energy systems that contribute most to the execution of specific activities.

Individual differences in fitness levels and variations in exercise economy may, however, lead to errors in the estimation of exercise intensities and energy system contributions when using the heart rate guidelines (Achten & Jeukendrup, 2003:526). Because of the limitations linked to using heart rate values alone to predict exercise intensities, researchers have measured oxygen uptake ($\dot{V}O_2$) and heart rates concurrently at a variety of intensities in the laboratory to provide more accurate guidelines for the heart rate values that reflect certain exercise intensities (Achten & Jeukendrup, 2003:525). The direct measurement of $\dot{V}O_2$ by indirect calorimetry and specifically by open-circuit spirometry during a graded maximal test allows researchers to identify two physiological gas exchange points, namely the aerobic threshold/ventilatory threshold (VT_1) and the anaerobic threshold/respiratory compensation point (RCP) (Foster & Cotter, 2006:69). The heart rates that correspond to the exercise intensities below the VT_1, between the VT_1 and RCP and above the RCP are then determined to classify the different exercise intensity heart rate zones (Foster & Cotter, 2006:73; Bompa, 1999:361). Currently no attempts have been made to apply this technique for determining the game intensities of any team sports. However, it has been used in individual sports such as cycling, where the research revealed that most of the racing time was spent in zone 2 (between VT_1 and RCP, moderate intensity), and considerably less time in zone 3 (above RCP, high intensity) during the last day of racing (Rodriguez-Marroyo *et al.,* 2009:182).

Despite the fact that all of the above-mentioned research findings seem to suggest that the demands of a rugby game need to be quantified for sport scientists to construct appropriate conditioning programs, no researchers have thus far attempted to quantify the rugby union games of a South African tertiary institution rugby union team. It is in light of this research background and identified shortcomings that the following research questions are posed: Firstly: What are the intensities of tertiary institution rugby games when making use of heart rates and graded maximal test values? Secondly: What are the positional differences in tertiary institution rugby game intensities when making use of heart rates and graded maximal test values?

Results of this study could possibly enable future coaches, rugby players and sport scientists of tertiary institution rugby teams to compile conditioning programs, specifically in accordance with the demands of rugby games.

2. OBJECTIVES

The objectives of this study were:

- To determine the intensities of tertiary institution rugby union games, by using heart rates and graded maximal test values.
- To determine the positional differences in tertiary institution rugby game intensities, by using heart rates and graded maximal test values.

3. HYPOTHESES

This study is based on the following hypotheses:

- When heart rates and graded maximal test values are used for determining the game intensities during tertiary institution rugby games, it will be found that significantly more game time will be spent in low and moderate heart rate zones than in the high-intensity heart rate zone,
- When heart rates and graded maximal test values are used for determining the game intensities during tertiary institution rugby games, it will be found that forwards will spend significantly more game time in the high-intensity heart rate zone compared to the backs, whereas the backs will spend significantly more game time in low and moderate-intensity heart rate zones compared to the forwards.

4. STRUCTURE OF DISSERTATION

The dissertation is submitted in article format as approved by the Senate of the North-West University and is structured as follows:

Chapter 1: Problem statement, hypotheses and objectives. A bibliography is provided at the end of the chapter in accordance with the guidelines of the North-West University.

Chapter 2: Literature review: The application of different methods to determine the game intensities of rugby union. A bibliography is provided at the end of the chapter in accordance with the guidelines of the North-West University.

Chapter 3: Article 1 – The use of heart rates and graded maximal test values to determine rugby union games intensities. The article will be presented for possible publication in the Journal of Strength and Conditioning Research. A bibliography is presented at the end of the chapter in accordance with the guidelines of the journal. Although not according to the guidelines of the journal, tables and figures will be included within the text so as to make the article easier to read and understand. Furthermore, the line spacing of the article will be set at 1.5 lines instead of the prescribed 2 lines.

Chapter 4: Article 2 – The use of heart rates and graded maximal test values to determine positional differences in rugby union game intensities. The article will be presented for possible publication in the Journal of Sports Sciences. A bibliography is presented at the end of the chapter in accordance with the guidelines of the journal. Although not according to the guidelines of the journal, tables will be included within the text so as to make the article easier to read and understand. Furthermore, the line spacing of the article will be set at 1.5 lines instead of the prescribed 2 lines.

Chapter 5: Summary, conclusions and recommendations.

Appendix A: The demographic and general information questionnaires, informed consent forms and standard incremental treadmill test data collection forms

Appendix B: The instructions for authors and an example of a published article from the Journal of Strength and Conditioning Research

Appendix C: The instructions for authors and an example of a published article from the Journal of Sports Sciences.

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CHAPTER 2

2 LITERATURE REVIEW: THE APPLICATION OF DIFFERENT METHODS TO DETERMINE THE GAME INTENSITIES OF RUGBY UNION

1. Introduction

Since rugby union became a professional sport in 1995, rugby players' fitness profiles as well as the intensity of rugby games have changed dramatically (Duthie *et al.*, 2003a:974). The physiological demands of rugby union are much more complex when compared to that of individual sports, because of the diverse nature of movement patterns in rugby games (Duthie *et al.*, 2003a:974). Actions such as tackling and rucking are performed rapidly and are fuelled by anaerobic sources, whilst the aerobic system promotes recovery between dynamic movements and provides energy for less intense activities such as walking and jogging (Luger & Pook, 2004:4). Coaches and sport scientists will, however, only be able to condition players specifically for the demands of rugby union if they are aware of the amount of work players need to perform at certain intensities during the game (Luger & Pook, 2004:2). Some of the methods that have been applied in recent years to determine the amount of work and work intensities of rugby games are time-motion analyses (Roberts *et al.,* 2008; Deutch *et al.*, 2007; Duthie *et al.*, 2005; Deutch *et al.*, 1998; McLean, 1992), heart rate recording and analyses (Deutsch *et al.*, 1998) as well as blood lactate analyses (Deutsch *et al.*, 1998; McLean, 1992). In view of the last-mentioned facts, the subsequent section will focus on a description of Rugby Union and the characteristics of the sport, as well as research that have investigated the application of different methods to determine the demands of rugby union and various other sports.

2. Description of Rugby Union

This section was compiled by making use of the following sources: Williams *et al.* (2005:5), Luger & Pook (2004:7) and Wikipedia (2009). Rugby union is a competitive outdoor contact sport played with a spheroid ball. The game consists of two halves with a duration of 40 min each. During the game time of 80 min, the ball is in play for only about 32 min (results of games played between 1999 and 2003). During this time 15 players of each team (with the exception of players being sent off for misconduct) compete for the ball. The positions the players fill during a game can be grouped into two main categories, namely: the forwards (1-8), consisting of the loose head prop (1), hooker (2), tight head prop (3), two locks (4+5), two flankers (6+7), an eighth man (8) and the backs (9-15), which consist of the scrum half (9), fly half (10), two wings (11+14), two centres (12+13) and a full back (15). Generally the forwards are viewed as the ball fetchers who engage in frequent scrummaging, mauling, rucking and tackling compared on the other hand to the backs (ball carriers) that usually run with the ball in hand. The game of Rugby Union is played on a grassy pitch with the field of play not exceeding a width of 70 m and a length of 100 m.

The game starts with the referee that gives a signal and one of the team's kickers that takes a drop kick on the halfway line (kick-off). The ball has to travel at least 10 m into the opposition half with the players on the kicking side that have to stay behind the ball when it is kicked. When the opposition gains possession of the ball, they can opt to either kick the ball forward or run forward with the ball in hand. The ball can be passed from one player to another, but players are not allowed to pass the ball forward. The team that is not in possession of the ball tries to gain possession by grabbing the player and bringing the player with the ball to ground (tackling). As soon as the player is brought to ground, he must release the ball so that both teams can compete for the loose ball (rucking). Play stops when an infringement of the law is committed, the player is out of the field of play or a team scores by touching the ball over the goal-line (a try) or kicks it over the crossbar of the goal posts (drop kick). When an infringement occurs, a scrum, free kick or penalty (depending on the nature of the infringement) is awarded to the non-infringing team. If the ball is out of the playing field (in touch) a line-out is awarded against the team that touched the ball last. If points are scored, the non-scoring team restarts the game with a kick-off. The game carries on in this fashion until the whistle blows for half time or the end of the match.

The subsequent section will be dedicated to the research that has focused on the analyses of rugby games by applying different methods.

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3. The analyses of rugby games

Rugby union players do not only have to exhibit great rugby skills, but also need to possess an above average fitness level (Scott *et al.,* 2003:173). The typical range for cycles of continuous play are between 5 and 63 sec with an average cycle lasting 23 sec (Luger & Pook, 2004:6). The average rest period lasts 42 sec with the longest periods of rest occurring after tries, penalty kicks at goal or when a player receives treatment for an injury (Luger & Pook, 2004:6). In order to create effective training programs for these players, the match demands of rugby have to be known. Researchers have used movement analyses (Roberts *et al.,* 2008; Deutch *et al.*, 2007; Duthie *et al.*, 2005; Deutch *et al.*, 1998; McLean, 1992), heart rates (Deutch *et al.,* 1998) and blood lactate values (Deutch *et al.,* 1998; McLean, 1992) to analyse the demands of rugby games. A summary of the researchers, competition level of players, number of matches and players analysed as well the methods of analyses applied in each study, are presented in Table 1.

From Table 1 it is apparent that time-motion analyses are the preferred method for determining the demands of rugby union. In view of this, the following section will mainly focus on time-motion analyses, but also on supplementary methods applied to analyse rugby union matches.

Table 1: Summary of information that relates to the studies that have analysed rugby union games

Authors	Competition level	Number of matches analysed	Number of players used in total	Method of analyses
Deutsch *et al.* (1998)	Elite under-19	4	24	Heart rate, blood lactate and time-motion analyses
Deutsch *et al.* (2007)	Professional	8	29	Time-motion analysis

Duthie *et al.* (2005)	Professional	16	47	Time-motion analysis
McLean *et al.* (1992)	International	5	Not available	Time-motion and blood lactate analyses
Roberts *et al.* (2008)	Elite	5	29	Time-motion analysis

3.1 The application of time-motion analyses to determine the demands of rugby union games

Time-motion analysis is an effective tool for gathering information regarding movement patterns and energy demands during rugby matches (Duthie *et al.,* 2003a:983). The calculation of the frequency, mean duration and total time spent in different activities is fundamental to time-motion analyses (Duthie *et al.,* 2005:523). The distances covered in each game are also of some interest (Duthie *et al.,* 2005:523). Researchers usually identify the most important activities performed during the match and categorise it into different intensity zones by means of time-motion analyses (Deutsch *et al.,* 1998:563). Table 2 provides a summary of the different activities in rugby union as well as the intensity zones each of the activities are categorized in.

Rugby union presents unique challenges when analysed, due to different movements performed, namely scrums, line-outs, tackles, rucks, mauls, just to name a few (Hughes & Franks, 2004:72). Researchers therefore need to cover the entire playing field when video recordings of games are to be collected. In this regard Roberts *et al.* (2008:826) made use of 5 cameras placed around the field to cover the total playing surface, together with a global cartesian coordinate system placed in one corner of the playing area. The mentioned equipment was used to calculate the total distance travelled by each player, the total distance travelled in each activity mode, the frequency of activities in each activity mode as well as the mean and maximum duration of each activity mode. The last-mentioned study on English premiership rugby players was the first study to report total distances run and changes in high-intensity activities during the course of a senior elite rugby union match (Roberts *et al.*, 2008:832). Overall the findings of this study were in line with those of previous studies (Deutch *et al.*, 2007; Duthie *et al.*, 2005; Deutch *et al.*, 1998; McLean, 1992) on rugby union. Larger distances (6 127 m *versus* 5 581 m) were covered by the backs when compared to the forwards because of their bigger engagement in activities such as walking and running, while forwards spent more time (7min:56sec *versus* 1min:18sec) on static exertion type of activities than backs (Roberts *et al.*, 2008:828). Also, the forwards performed more bouts of high-intensity activities than backs (131 *versus* 82) with a longer mean duration for each bout (4.1sec *versus* 2.3sec) (Roberts *et al.*, 2008:828). This study also accentuated the importance of players' ability to accelerate and decelerate effectively during matches (Roberts *et al.,* 2008:831). Roberts *et al.* (2008:831) therefore concluded that forwards spent more of the total game time in high-intensity activities and less time in low intensity activities (high 12%, low 88%) respectively, compared to the backs (high 4%, low 96%).

Table 2: Summary of the different activities that take place during a rugby union game and the intensity zones of categorisation

Authors	**Intensity zones**	
	Low	**High**
Deutsch *et al.* (1998)	Walking, jogging and utility movements (shuffling sideways or backwards to change field position)	Cruising, sprinting, rucking, mauling and scrummaging
Deutsch *et al.* (2007)	Standing, walking, jogging and utility movements (shuffling sideways or backwards to change field positions)	Cruising, sprinting, rucking, mauling, scrummaging and tackling
Duthie *et al.* (2005)	Standing, walking and jogging	Striding, sprinting, static exertion (scrummaging, rucking, mauling and tackling), jumping, lifting and tackling
McLean (1992)	Standing, walking and jogging	Run with elongated strides,

		sprinting and intense activities (excluding running)
Roberts *et al.* (2008)	Standing (0-0.5 m/sec), walking (0.5-1.7 m/sec), jogging (1.7-3.6 m/sec) and medium intensity running (3.6-5.0 m/sec)	High-intensity running (5.0-6.7 m/sec), sprinting (>6.7 m/sec), static exertion (scrummaging, rucking, mauling and tackling)

In three other studies the cameramen followed one player at a time during the rugby matches (Deutsch *et al.,* 2007; Duthie *et al.,* 2005; Deutsch *et al.,* 1998). The camera positions in two of the studies varied between 5 and 15 m from the field at an elevation of 3 to 16 m, depending on the venue (Deutsch *et al.,* 2007:462; Deutsch *et al.,* 1998:563). In the study of Duthie *et al.* (2005:524) the video cameras were positioned in the grandstand approximately 20 m above the playing field at the mid-point of the rugby field. The last-mentioned studies all applied time-motion analyses to collect data with regard to the total time, relative time, frequency and average duration of each activity mode during the different rugby matches. The work:rest ratio's for each rugby match were also calculated by dividing the duration of each interval of high-intensity work by the duration of the following rest interval for each passage of play (Deutsch *et al.,* 2007:463). Deutsch *et al.* (1998:564) also calculated the distances covered during each activity mode by determining the duration and speed of each activity (time x speed = distance). The average speed of each individual player's movements were measured with electronic timing gates before each training session in order to calculate the distance travelled for each activity during the match (Deutsch *et al.,* 1998:564).

Deutsch *et al.* (2007:467) found that the forwards spent significantly more total time (12-13%) in high-intensity activities than the backs (4.5%), due to their greater involvement in rucking, mauling and scrummaging. As expected, the forwards spent 80-90% of their high-intensity activities on rucking/mauling, scrummaging and tackling, compared to the backs that spent 60-70% of their high-intensity work on running type of activities (Deutsch *et al.*, 2007:467). The mean work period for backs was approximately 5 sec with the mean rest period between 80 and 110 sec (work-to-rest ratio of 1:16-22). On the other hand the mean work period for forwards was also 5 sec, but the mean rest period was found to be approximately 30 to 40 sec (work-to-rest ratio of 1:6-8) (Deutsch *et al.,* 2007:470). From these results Deutsch *et al.* (2007:471) concluded that the anaerobic glycolytic energy pathway played an important role in contributing to the energy requirements of the different activities players performed, especially among the forwards. The aerobic energy system will, however, also play an important role, particularly when the length of recovery periods are shorter than 3 min, which will lead to a complete inhibition of the anaerobic glycolytic and creatine phosphate energy pathways (Deutsch *et al.,* 2007:471).

Duthie *et al.* (2005:527) reported that the majority of work periods during a rugby game were less than 4 sec long and the rest periods less than 20 sec. Across all positions high-intensity, short duration work efforts (< 4 sec on average) were frequently performed (35% of the time), rarely exceeding 16 sec and interspersed with less than 20 sec of rest between bouts. These results accentuate the findings of Deutsch and his colleagues (2007:470), namely that rugby requires a high level of aerobic conditioning to facilitate the recovery between high-intensity bouts during which energy is derived from anaerobic sources (Duthie *et al*., 2005:529).

In an older study, Deutsch *et al.* (1998:569) found that the forwards performed more total work (11.2 min) than the backs (3.5 min) during the course of a match. As a result of their high-intensity work rates, the forwards maintained a higher work:rest ratio (1:1.4) compared to the backs (1:2.7) (Deutsch *et al.,* 1998:567). One-third of the work periods for the forwards were followed up by an equal or shorter period of rest, resulting in insufficient time for the replenishment of creatine phosphate stores and a heavier reliance on the anaerobic glycolysis energy pathway (Deutsch *et al.,* 1998:569). Despite an overall lower exertion, backs covered greater distances (5 640 m) than forwards (4 240 m) (Deutsch *et al*., 1998:566).

McLean (1992:287) used live television recordings to measure the distance covered during each activity mode by using visual cues on the field. He also timed the duration of different activities with a digital stopwatch. The average speed for each activity was calculated by using the distance and duration of the activities previously mentioned. McLean (1992:288) found the average duration of passages of play to be 19 sec. It was also found that the ball was in play for only 29 min out of the total match time of 80 min (McLean, 1992:288). Furthermore, he also reported that the rucks and mauls outnumbered scrums by 56% and line-outs by 44%. The time-motion analyses' results enabled McLean (1992:290) to conclude that players spent 37% of the total match time on work periods that were longer than the rest periods and 63% of the time on rest periods that were longer than the work periods. He also noted that the work:rest ratios which occurred more frequently were 1:1-1.9 (26.6%) and 1-1.9:1 (20.2%) (McLean, 1992:289). Eight passages of play involved six consecutive passages of play where the duration of work exceeded rest (a total of 137 sec of work to 71 sec of rest) (McLean, 1992:289). The number of consecutive passages of play with work greater than rest periods were six and the average was four (McLean, 1992:290).

The validity and accuracy of time-motion analyses to determine the demands of rugby games have, however, been questioned (Deutsch *et al.,* 2007:469; Duthie *et al.,* 2005:529; Duthie *et al.,* 2003a:983). During time-motion analyses, movement patterns are simplified by grouping it into categories, while actual play involves a combination of dynamic tasks, skills and tactics (Duthie *et al.,* 2003a:983). Time-motion analyses' results may therefore not reflect the actual demands of a specific game due to measurement errors (Duthie *et al.,* 2003a:983). A study by Duthie *et al.* (2003b:259) in which the reliability of time-motion analyses was evaluated showed that time-motion analyses are moderately reliable and that this should be considered when assessing movement patterns in rugby. Deutsch *et al.* (2007:469) noted that time-motion analyses is limited in its ability to assess the specific demands of certain activities as well as in its ability to describe the combination of activities in relation to aspects such as skill, decision making and tactics. According to Duthie *et al.* (2005:529), researchers would also not be able to accurately quantify the contacts with opposition players by means of video analyses due to the lack of direct intensity measurements. Players will therefore be able to ruck, maul and scrum without necessarily exerting themselves maximally, which is something researchers would not be aware of when making use of video analysing data alone. In view of the mentioned uncertainties with regard to the reliability of time-motion analyses, researchers have proposed the measurement and use of heart rate and blood lactate values to strengthen the accuracy of the video analyses' results (Deutsch *et al.,* 1998; McLean, 1992).

3.2 Blood lactate analyses during rugby union matches

The use of blood lactate samples to determine exercise intensities is a widely accepted and prescribed technique in endurance sports (Foster & Cotter, 2006:73). Researchers have, however, also applied this technique to determine the exercise intensities of rugby union games (Deutsch *et al.,* 1998; McLean, 1992). In this regard, McLean (1992:287) collected five blood samples of six players, respectively during stoppages in match play. The blood lactate analyses took place by means of a semi-automated analyzer, 3 and 5 minutes after the samples had been collected. The peak blood lactate values for each player were determined by means of a maximal treadmill test three days after each of the matches. The highest blood lactate concentrations noted for the maximal treadmill tests ranged between 5.8 and 9.8 mM/L blood (McLean, 1992:291). During the match, however, the blood lactate levels varied between 56 and 85% of the maximum blood lactate levels (McLean, 1992:293). The collection of blood samples was, however, dictated by stoppages during play and was not specific to passages of high-intensity periods (McLean, 1992:294). Both the blood lactate concentrations and the work:rest ratio's led McLean (1992:293) to conclude that considerable demands are placed on the anaerobic metabolism of rugby players. Although McLean's study (1992) produced results similar to those of previous studies, the data may not accurately reflect the demands of the current game due to rule changes that were implemented after 1995 (Duthie *et al.,* 2003a:983). These rule changes have made the game more "open", faster and more attractive to spectators, which would probably increase the intensities of games and also have a considerable effect on the blood lactate responses of players.

In another study Deutsch *et al.* (1998:568) collected blood samples once or twice during each half of play when breaks occurred as well as during the half and full time. They found blood lactate concentration values of between 6.2 and 8.8 mM/L blood, which do not necessarily give a reflection of the rugby match itself, because of the fact that the blood samples were collected during breaks and after the match.

The collection of blood samples for blood lactate analyses offers some logistical problems during rugby matches due to the fact that blood sampling is dictated by stoppages in play (Duthie *et al.,* 2003a:986). Therefore if the time span after high-intensity bouts for blood sampling is too long, the blood lactate will be metabolised and will not be a true representation of the overall demands of the game (Duthie *et al.,* 2003a:986). In view of these issues, it can be recommended that researchers apply alternative methods in addition to blood lactate analyses, in order to improve the accuracy of time-motion analyses.

3.3 Heart rate analyses during rugby union matches

The introduction of portable wireless heart rate monitors made it possible for researchers and sport-related professionals to monitor and use players' heart rates as an intensity measure of on-field activities (Achten & Jeukendrup, 2003:525). Only one study could be traced that reported on the heart rate values of rugby players during a rugby match. In this regard Deutsch *et al.* (1998:563) grouped rugby players' heart rates into 4 categories, namely: > 95% of HR_{max} (heart rate maximum) as the maximal intensity category; 85–95% of HR_{max} as the supra-threshold intensity category; 75–84% of HR_{max} as the anaerobic threshold intensity category and < 75% of HR_{max} as the sub-threshold intensity category. Deutsch *et al.* (1998:563) defined the maximal heart rate of each player as the maximum value each player obtained during a rugby match. The relative time spent in high-intensity activities by the 4 positional groups were: 58.4% (props and locks), 56.2% (back row forwards), 40.5% (inside backs) and 33.9% (outside backs) respectively (Deutsch *et al.*, 1998:565). According to the heart rate data of Deutsch *et al.* (1998:567) the props, locks and loose forwards spent up to 20% of match time in the maximal intensity zone compared to the backs who spent more time in the moderate to low intensity zones, which may be a reflection of the lower demands of back-line play compared to front-row play (Deutsch *et al.,* 1998:567).

Shortcomings with regard to the use of heart rate values to determine the demands of rugby union games have also been highlighted. Individual differences in fitness levels and variations in exercise economy may lead to errors in the estimation of exercise intensities and energy system contributions when using heart rate guidelines alone (Achten & Jeukendrup, 2003:526). Generalizing the intensity zones for all the players based on maximum heart rate may therefore not be the most accurate method of predicting the game intensities.

3.4 Effects of rule changes on rugby union matches

Although all of the above-mentioned studies made a great contribution towards understanding the demands of rugby union, the International Rugby Board (IRB) introduced a number of rule changes in 1999 to improve the safety and competitiveness of rugby union. Williams *et al.* (2005) did a study to investigate the effect of rule changes on overall game and ball in play time in rugby union matches, which will directly impact the demands of the game. They observed games played in the Six Nations, Tri Nations, European Cup and Super 12 competitions during a five-year period (1999 – 2005)(Williams *et al.,* 2005). There was a significant increase in game time from 1999 (87 min:00 sec) to 2003 (90 min:52 sec) (Williams *et al.*, 2005:7). This increase could be attributed to the introduction of more match officials, more substitutions and more injuries (Williams *et al.*, 2005:8). There was also a significant increase in ball in play time, with an increase of 3 min:09 sec from 1999 to 2003. The rule changes of January 2000 are thought to be the biggest contributor to these increases (Williams *et al.*, 2005:9). These rule changes include changes to improve recycling at the breakdowns, the turnover scrum rule and improved lifting rules during line-outs (Williams *et al.,* 2005:8). Other minor rule changes have been made since 2003, but their effects on the game have not yet been studied.

4. The application of heart rates and graded maximal test values to identify the competition demands of other sports

In the past two decades, the use of portable heart rate monitors have allowed scientists to estimate the exercise intensities of training sessions and competitions, based on the linear relationship that exist between the heart rates and metabolic exercise intensities (Esteve-Lanao *et al.,* 2005:496). A method that can be applied to determine the intensities during training and competitions is by categorising intensities into different zones according to referent heart rate values obtained during cardiorespiratory exercise testing (Esteve-Lanao *et al.,* 2005:496). By using oxygen uptake ($\dot{V}O_2$) and heart rate concurrently on a variety of intensities in the laboratory, exercise intensity zones can be established and used to determine the demands of competition (Achten & Jeukendrup, 2003:525). The following measures can be attained by using the direct measurement of $\dot{V}O_2$ by indirect calorimetry and specifically by open-circuit spirometry during a graded maximal test: the rate of oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), minute ventilation ($\dot{V}_E$) and the respiratory exchange ratio (RER) (Esteve-Lanao *et al.,* 2005:498). Two physiological gas exchange points can then be identified, namely the aerobic threshold/ventilatory threshold (VT_1) and the anaerobic threshold/respiratory compensation point (RCP) (Foster & Cotter, 2006:69). The VT_1 is determined by using the criteria of an increase in $\dot{V}_E/\dot{V}O_2$ with no increase in $\dot{V}_E/\dot{V}CO_2$ and departure from the linearity of $\dot{V}_E$ (Chicharro *et al.,* 2000:452). The RCP is the point that corresponds to an increase in both $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$ (Chicharro *et al.,* 2000:452). Several researchers have applied this method to analyze the competition intensities of numerous sports, namely cross-country running (Esteve-Lanao *et al.,* 2005), cross-country skiing (Seiler & Kjerland, 2006) and road cycling (Rodriguez-Marroyo *et al.,* 2009; Lucia *et al.,* 1999).

Esteve-Lanao *et al.* (2005:496) quantified the relationship between total training load and running performance during the most important competitions of the cross-country championship season by using the intensity zones associated with the aerobic and anaerobic thresholds. They found that endurance runners spent the majority (71%) of their training time at low intensities, with moderate and high intensity work performed for 21% and 8% of the total training time respectively (Esteve-Lanao *et al.,* 2005:500). A negative correlation was also found between the total time spent in the low intensity zone and performances during cross-country races (Esteve-Lanao *et al.,* 2005:500).

Similar to Esteve-Lanao and his colleagues' study (2005), Seiler and Kjerland (2006:49) also quantified the training intensities of a group of well-trained junior cross-country skiers by using the two physiological thresholds. The researchers determined that 91% of all training time was spent in the first intensity zone (below VT_1), 6.4% in zone 2 and only 2.6% in zone 3 when using the total time-in-zone method (Seiler & Kjerland, 2006:52). However, when they applied the session-goal method (each training session was analyzed according to a specific goal) they found that 75% of the training sessions were spent in zone 1 (below VT_1), 5 – 10% of the session in zone 2 (between VT_1 and RCP) and 15 – 20% of sessions in zone 3 (above RCP) (Seiler & Kjerland, 2006:53).

Heart rate also remains the parameter of choice for studies that analysed the competition intensities of cyclists (Rodriguez-Marroyo e*t al.,* 2009; Lucia *et al.,* 1999). Rodriguez-Marroyo *et al.* (2009:182) analyzed and compared the workloads exerted by professional cyclists in 5-day, 8-day and 21-day stage races and reported average VT_1 and RCP of 62% and 83% of cyclists' $\dot{V}O_{2max}$ values respectively. This research also revealed that most of the racing time was spent in the moderate-intensity zone (between VT_1 and RCP), and considerably less time in the high-intensity zone (above RCP) during the last day of racing (Rodriguez-Marroyo *et al.,* 2009:182). An evaluation of the heart rate response of 8 professional cyclists during the 3-week Tour de France showed that the relative contribution of each of the different heart rate zones (low, medium and high) were 70%, 23% and 7% respectively (Lucia *et al.,* 1999). The professional cyclists obtained VT_1 and RCP values of 70% and 90% of their $\dot{V}O_{2max}$ respectively. Lucia *et al.* (1999:167) further concluded that the competition exercise intensities were particularly high during the time trials and mountain stages.

From the above-mentioned research results it is clear that the combined use of competition heart rates and the gas-exchange values obtained during an incremental running or cycling test to determine the intensities and demands of different sports are a well-known practice. Despite this, no researcher has to date made any attempt to quantify the game intensities of team sport participants by applying the last-mentioned technique.

5. Conclusions

In this review the author attempted to give a thorough overview of rugby union as a sport as well as the research pertaining to the use of time-motion analyses to determine and describe the demands of rugby union games. The author also gave attention to other methods applied in combination with time-motion analyses in order to further strengthen the accuracy and validity of the match analyses results. In this regard two methods that have been recommended to analyse and describe rugby match intensities and demands, are the blood lactate and heart rate analyses methods. Due to the shortcomings identified with regard to the application of the above-mentioned methods, the author concluded this review by investigating the combined use of heart rates and graded maximal test values to analyse the competition demands of various sports and to look into the probability of using the last-mentioned method to analyse and describe the match intensities of rugby players.

Collectively, the author showed that the demands of rugby union match play are much more complex to analyse compared to the demands of individual sporting codes due to the wide range of movements performed during matches and the numerous activities that take place during match play. Most researchers that have investigated the match play demands of rugby union applied the time-motion analyses technique. The majority of research conducted that applied this technique indicated that rugby union players are mainly fuelled by the anaerobic glycolitic system, with the aerobic system playing a secondary role during short rest periods. There are also distinct differences between the forwards and backs, with the forwards that show a higher work:rest ratio than the backs.

The validity and accuracy of time-motion analyses as a method for determining the demands of rugby match play have, however, come under scrutiny due to measurement errors, the limited ability of time-motion analyses to assess specific demands and the moderate reliability of time-motion analyses. All of the last-mentioned shortcomings with regard to time-motion analyses have compelled researchers to apply the blood lactate and heart rate analyses methods coupled with the time-motion analyses method to strengthen the accuracy of the match analyses results. Blood lactate values of between 3.6 and 9.8 mM/L were reported for match play among rugby players, whereas heart rate values ranged between 75 and 95% of the maximum heart rate, with the majority of back-line players who displayed heart rate values that could be categorized as moderate to high-intensity heart rates during the match. When compared, the forwards were the group that displayed a higher percentage of high-intensity heart rates. Despite the notion that blood lactate and heart rate analyses would strengthen the time-motion analyses results, the accurateness of blood lactate analyses results can be questioned in view of the fact that blood lactate samples can only be taken during stoppages in play which would lead to lower blood lactate values when compared to the blood lactate values taken during play. Similarly, the application of heart rate guidelines to estimate exercise intensities would give rise to errors when determining game intensities.

These limitations with regard to the application of heart rates, blood lactate and game-motion analyses to determine rugby game intensities have convinced the author of this review to also investigate the suitability of other methods to determine the match play demands of rugby union players. The combined use of heart rates and the graded maximal test gas analyses values of players seem to be a good method to determine the rugby match demands. Although, the use of this method during individual sports such as cross country running and skiing as well as road cycling has been well documented, but no researchers have yet attempted to apply this method for determining the match demands of rugby union players. In view of this limitation and the fact that at present the literature contains no up to date data with regard to the match profiles of rugby players, it is imperative that researchers contribute to the field of sport science in order to provide new knowledge to the existing science of rugby union.

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CHAPTER 3

3 THE USE OF HEART RATES AND GRADED MAXIMAL TEST VALUES TO DETERMINE RUGBY UNION GAME INTENSITIES

TITLE: THE USE OF HEART RATES AND GRADED MAXIMAL TEST VALUES TO DETERMINE RUGBY UNION GAME INTENSITIES

RUNNING HEAD: THE DETERMINATION OF RUGBY UNION GAME INTENSITIES

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THE USE OF HEART RATES AND GRADED MAXIMAL TEST VALUES TO DETERMINE RUGBY UNION GAME INTENSITIES

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ABSTRACT

The aim of this study was to determine the intensities of tertiary institution rugby union games, using heart rates and graded maximal test values. Twenty-one rugby players performed a standard incremental maximal oxygen uptake ($\dot{V}O_{2max}$) test to the point of exhaustion in the weeks between three rugby matches. The heart rates that corresponded to the first and second ventilatory thresholds were used to classify the heart rates into low, moderate and high-intensity zones. The heart rates recorded through heart rate telemetry during the matches were then categorized into the different zones. The average heart rates for the different intensity zones, as well the percentages of the maximum heart rate (HR_{max}) were as follows: low – 141 to 152 bpm (76.2 to 82.0% HR_{max}), moderate – 153 to 169 bpm (82.7 to 91.4% HR_{max}) and high – 170 to 182 bpm (91.9 to 100% HR_{max}). The percentages of time players spent in the different intensity zones were: 22.8% for the low, 33.6% for the moderate and 43.6% for the high-intensity zones, respectively. Significant differences ($p<0.05$) were found by means of the dependant t-test between the low and high-intensity zones for the second halves, between the low and moderate as well as between the low and high-intensity zones for the matches overall. To conclude, the results of the study showed that the last-mentioned method can be used to determine the intensities of tertiary institution rugby union games. It also revealed that tertiary institution rugby games are categorized by significantly more high-intensity activities than was previously reported by other rugby match analysing-related studies.

KEY WORDS*:* thresholds, game analysis, oxygen uptake

INTRODUCTION

The fitness potential of rugby players can only be optimised if sport scientists and other sport-related professionals understand the diverse nature of rugby and construct sport specific training regimens accordingly (5). The physiological demands of rugby union are much more complex compared to those of individual sports (7) because of the wide range of movement patterns and the frequent bouts of physical contact that occur during rugby games. The most common methods used in recent years to determine the amount of work and work intensities of rugby games are time-motion analyses (5,6,9,16,17), heart rate recording and analyses (5) as well as blood lactate monitoring (5,16).

Time-motion analyses are extensively used to assess the demands of team sports (8). It quantifies the movements of players during matches by dividing the movement patterns into categories (7), such as low-intensity activities (standing, walking and jogging) and high-intensity activities (cruising, sprinting and static exertions such as scrums, rucks and mauls) (5,9,16,17). Although, these studies have provided practitioners with insight with regard to the demands of rugby union games, the validity and accuracy of time-motion analyses have been questioned. In this regard Duthie et al. (8) showed that video-based time-motion analyses are only moderately reliable as a tool to determine the demands of rugby union. Furthermore, Duthie et al. (9) concluded that time-motion analyses do not allow researchers to accurately quantify the intensities of movements such as rucks, mauls and scrums due to the lack of direct intensity measurements. Players will therefore be able to ruck, maul and scrum without necessarily exerting themselves maximally, in spite of the fact that these types of movements are generally categorized as high-intensity movements. In view of the named uncertainties concerning the reliability of time-motion analyses, researchers have proposed the measurement and use of heart rates and blood lactate values in an attempt to strengthen the accuracy of the time-motion analyses' results (5,16).

However, the use of blood lactate and heart rate values to determine the demands of rugby union match play have also come under scrutiny. Blood lactate sampling is dictated by stoppages in match play (7), which may negatively influence the accuracy of the blood lactate values. This statement is especially relevant in cases where the time span after high-intensity bouts for blood sampling is too long and the blood lactate is metabolized before measurements are taken. In cases such as these, blood lactate will not give a true reflection of the demands of rugby union matches (7).

Although some researchers have attempted to increase the accuracy of rugby match analyses by monitoring and analysing rugby players' in-game heart rates (5), certain shortcomings with regard to the use of heart rate values to determine the demands of rugby union games have also come under the spotlight. Individual differences in fitness levels and variations in exercise economy among the players may for example lead to errors when making use of heart rate guidelines alone to estimate exercise intensities and energy system contributions (1). Furthermore, generalizing intensity zones for all players by making use of maximum heart rates may not be the most accurate way of determining the different zones (12).

In view of the afore-mentioned limitations with regard to the use of time-motion, blood lactate and heart rate analyses for determining rugby match demands, researchers have been compelled to investigate other suitable methods. One method which has been of particular interest is the combined use of athletes' heart rates and the results of a standard graded maximal oxygen uptake test to the point of exhaustion to determine the competition demands of subjects. The direct measurement of oxygen uptake ($\dot{V}O_2$) by indirect calorimetry and specifically by open-circuit spirometry during a graded maximal test allows researchers to identify two physiological gas exchange points, namely the aerobic threshold/ventilatory threshold (VT_1) and the anaerobic threshold/respiratory compensation point (RCP) (11). The heart rates that correspond to the exercise intensities below the VT_1, between the VT_1 and RCP and above the RCP are then determined to categorize the intensity zones in low, moderate and high-intensity zones respectively (14). Until now, the last-mentioned method has only been used to quantify the competition demands of individual sports such as cross-country running (10), skiing (19) and road cycling (13,18). Currently no attempts have been made to use this method to determine the game intensities of any team sports.

In light of the above-mentioned discussion, which shows that the accuracy of time-motion, blood lactate and heart rate analyses for determining rugby game intensities can be questioned, the purpose of the present study was to determine the intensities of tertiary institution rugby union games by making use of the heart rates and graded maximal test values of the players. These results will assist coaches and other sport professionals in gaining a better understanding of what truly happens during rugby union matches

METHOD

Experimental Approach to the Problem

The specific hypothesis under scrutiny was that tertiary institution rugby games will be categorized by significantly more low and moderate-intensity activities compared to high-intensity activities. A cross-sectional experimental design was used to test the hypothesis of this study. Subjects were required to complete a standard incremental running test to the point of exhaustion in the period between rugby games. The heart rate values of each player were recorded during three rugby games played on the grounds of the institution responsible for the research.

Subjects

Twenty-one male rugby union players from the first and second rugby teams of the North-West University (Potchefstroom Campus – South Africa) were selected for this study. The characteristics of the subjects who participated in the study are presented in Table 1. For the players' data to be included in the study, they had to spend at least 50% (one half) of the game on the field; they had to complete a standard incremental running test to the point of exhaustion at least two weeks before or after the game and they had to be injury free at the time of testing. All players not adhering to these criteria were excluded from the study. The players' data were collected during three separate matches, with between four and nine players monitored during each match. The objectives of the study were explained to the players, after which they all completed an informed consent form. Approval for conducting the research was granted by the Ethics Committee of the North-West University.

TABLE 1. Physical characteristics of subjects*

Parameters	Subjects (*n = 21)*	Range
Age (y)	22.2±1.2	20.0-25.0
Body stature (cm)	182.3±7.1	171.6-197.4
Body mass (kg)	97.6±12.9	81.8-123.6

*Values are mean±*SD*.

Procedures

Standard incremental maximal oxygen uptake ($\dot{V}O_{2max}$) test to the point of exhaustion. A standard incremental maximal oxygen uptake test was conducted by means of open-circuit spirometry and computerized instrumentation in the laboratory. Each of the players performed the standard incremental test to the point of exhaustion on a Woodway Pro XL treadmill (Woodway, W229 N591, Foster Ct, Waukesha, WI). Prior to each standard incremental test the players warmed up on the treadmill for 5 minutes at a speed of 10 $km{\cdot}h^{-1}$ after which the speed was increased to 15 $km{\cdot}h^{-1}$ for a duration of 10 seconds. Static stretches, which involved the following body parts, were then executed for a duration of 20 seconds per stretch: shoulders, arms, chest, the upper as well as the lower legs. At commencement of the standard incremental test the first 2 minutes were completed at a running speed of 8 $km{\cdot}h^{-1}$, after which the treadmill speed was increased to 10 $km{\cdot}h^{-1}$ and by 1 $km{\cdot}h^{-1}$ every minute after the first two minutes. Exhaled air was continuously sampled by an Oxycon Pro static ergospirometry system (Jaeger Oxycon Pro, Viasys, 22745, Savi Ranch Parkway, Yorba Linda, CA, USA) and the rate of oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), minute ventilation ($\dot{V}_E$) and the respiratory exchange ratio (RER) were calculated every 5 seconds by an on-line computer system. The Oxycon Pro was calibrated in accordance with the manufacturer's specifications at the beginning of each test day. The test was stopped if the player indicated that it had to be stopped or if the criteria for reaching the $\dot{V}O_{2max}$ value had been achieved (e.g. a RER-value higher than 1.10 at test termination; oxygen consumption ceased to rise and reached a plateau or began to fall even though the work rate continued to increase or the maximal age specific heart rate was reached) (4,15). Throughout the test, heart rate was recorded for each 5-second period by means of a Fix Polar Heart Rate Transmitter Belt (Polar electro OY, Kempele, Finland).

Ventilatory threshold point (VT_1) and respiratory compensation point (RCP). Two physiological gas exchange points were identified. The VT_1 was determined using the criteria of an increase in $\dot{V}_E/\dot{V}O_2$ with no increase in $\dot{V}_E/\dot{V}CO_2$ and departure from the linearity of $\dot{V}_E$ (3). The RCP was taken as the point that corresponds to an increase in both $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$ (3). Two independent experienced researchers visually detected VT_1 and RCP. The different gas exchange phases were used to determine the heart rates that correspond to the three exercise intensities (3). Heart rates that corresponded to the exercise intensities below VT_1 were classified as low-intensity heart rates; heart rates that corresponded to the exercise intensities between VT_1 and RCP were classified as moderate-intensity heart rates and heart rates that corresponded to the exercise intensities above RCP were classified as high-intensity heart rates (14).

Rugby game heart rates. The heart rates of players were recorded at 4-second intervals during matches using the Hosand TM Pro telemetry heart rate monitoring system (Hosand Technologies Srl, Verbania, Italy). An electrode belt was strapped around the chest at the lower sternum of each player before the start of each match. The heart rate signal was then downloaded to a PC during each of the matches. The total match time was made up by the periods of match play activities as well as stoppages in play (excluding the half time interval), which in certain cases led to total match times being longer than 80 minutes.

Statistical Analysis

The Statistical Consultation Services of North-West University (Potchefstroom Campus) determined the statistical methods and procedures for the analyses of the research data. The Statistical Data Processing package (20) was used to process the collected data. Firstly, the heart rates obtained from each player during the matches were categorized into the three intensity zones (low, moderate and high) according to the standard incremental oxygen uptake test results. The times spent in the different zones were then expressed as a percentage of the total game time (excluding the time before the games and half-time). Secondly, the descriptive statistics (averages, minimum, maximum and standard deviation values) were calculated for each variable. Lastly, a dependant t-test was done to establish whether significant differences occurred between the intensities of each half. The level of significance for the t-test was set at $p < 0.05$.

RESULTS

The Standard Incremental Test values

The results from the standard incremental tests are presented in Table 2. The players achieved an average $\dot{V}O_{2max}$ value of 42.7±6.8 ml·kg^{-1}·min^{-1} with an average maximum heart rate value of 185±7.0 bpm. The first gas exchange point, the VT_1, occurred at an average heart rate of 153 bpm which was calculated to be 82.7% of the maximum heart rate. On the other hand, the RCP occurred at an average heart rate of 169 bpm and at 91.4% of the maximum heart rate. The heart rates for the different intensity zones were determined to be 141-152 bpm, 153-169 bpm and 170-185 bpm for the low, moderate and high-intensity zones respectively.

Match analyses

Table 3 shows the descriptive statistics for all the match analyses-related measurements. The average heart rate recorded for all the matches was 165 bpm, which falls within the moderate-intensity zone when categorized according to the heart rate zones presented in Table 2. Furthermore, the average maximum heart rate achieved during the games was 192±8.8 bpm which is higher than the mean maximum heart rate achieved during the incremental test (185±7.0 bpm). Of the total possible game time of 80 minutes, players only spent an average of 56min:23s±16min:55s on the playing field.

TABLE 2. Standard incremental test-related measurements of subjects

Parameters	Subjects (*n = 21)*	Range
$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	42.70±6.8	24.9-55.1
HR_{max} (bpm)	185.10±7.0	173-198
RER_{max}	1.25±0.0	1.15-1.30
VT_1 (% $\dot{V}O_{2max}$)	70.70±8.6	49.1-85.4
VT_1 (ml·kg^{-1}·min^{-1})	29.50±6.0	16.0-39.8
VT_1 (km·h^{-1})	9.90±1.2	8.0-11.0
VT_1 (RER)	0.98±0.1	0.88-1.09
VT_1 (bpm)	153.00±12.0	129-171
VT_1 (% HR_{max})	82.70±4.2	70.9-88.0
RCP (% $\dot{V}O_{2max}$)	85.40±5.7	71.2-94.4
RCP (ml·kg^{-1}·min^{-1})	36.40±6.0	23.2-46.6
RCP (km·h^{-1})	12.40±1.1	11.0-14.0
RCP (RER)	1.06±0.1	1.00-1.18
RCP (bpm)	169.00±10.9	148-186
RCP (% HR_{max})	91.40±3.4	81.3-96.8
Low-intensity HR zone (bpm)	141-152	115-170
[% HR_{max}]	[76.2-82.0]	
Moderate-intensity HR zone (bpm)	153-169	129-186
[% HR_{max}]	[82.7-91.4]	
High-intensity HR zone (bpm)	170-185	148-198
[% HR_{max}]	[91.9-100.0]	

$\dot{V}O_{2max}$ - maximum oxygen uptake; HRmax - maximum heart rate; RERmax - maximum respiratory exchange ratio; VT1 (% $\dot{V}O_{2max}$) - ventilatory threshold expressed as a percentage of the maximum oxygen uptake; VT1 (ml·kg^{-1}·min^{-1}) - oxygen uptake at the ventilatory threshold; VT1 (km·h^{-1}) - treadmill speed at ventilatory threshold; VT1 (RER) - respiratory exchange ratio at ventilatory threshold; VT1 (bpm) - heart rate at the ventilatory threshold; VT1 (% HRmax) - ventilatory threshold expressed as a percentage of the maximum heart rate; RCP (% $\dot{V}O_{2max}$) - respiratory compensation point expressed as a percentage of the maximum oxygen uptake; RCP (ml·kg^{-1}·min^{-1}) - oxygen uptake at the respiratory compensation point; RCP (km·h^{-1}) - treadmill speed at the respiratory compensation point; RCP (RER) - respiratory exchange ratio at the respiratory compensation point; RCP (bpm) - heart rate at the respiratory compensation point; RCP (% HRmax) - respiratory compensation point expressed as a percentage of the maximum heart rate; %HRmax - percentage of the maximum heart rate.

TABLE 3: Descriptive statistics for all the match analyses-related variables

Variable	Mean	Range
HR_{max} (bpm)	192.2±8.8	176.0-207.0
HR_{avg} (bpm)	165.0±12.3	138.5-181.2
Game time (min:s)	56:23±16:55	32:24-81:00

HR_{max} - maximum heart rate; HR_{avg} - average heart rate.

Figure 1 shows the mean time expressed as a percentage of the total game time that was spent in the different intensity zones during the first and second halves, as well as during the entire match. From Figure 1 it is apparent that players spent the majority of time during matches in the high-intensity zone. There were no significant differences between the percentages of time spent in the different intensity zones during the first halves of the different matches. There was, however, a significant difference between the percentages of time spent in the low (23.2%) and high-intensity zones (37.4%) respectively during the second halves of the different matches. With an analysis of the total match time, significant differences ($p<0.05$) were observed between the percentage of time spent in the low compared to the moderate-intensity zones (22.8 *versus* 33.6%), as well as the percentage of time spent in the low compared to the high-intensity zones (22.8 *versus* 43.6%).

The duration of time players spent in each of the intensity zones are presented in Table 4. The mean total time spent in the different intensity zones during the matches is as follows: 15min:06s, 24min:05s and 29min:38s for the low, moderate and high-intensity zones respectively. The mean duration of high-intensity bouts during the entire match was 1min:17s, with the mean duration of both moderate and low-intensity bouts being 29 seconds.

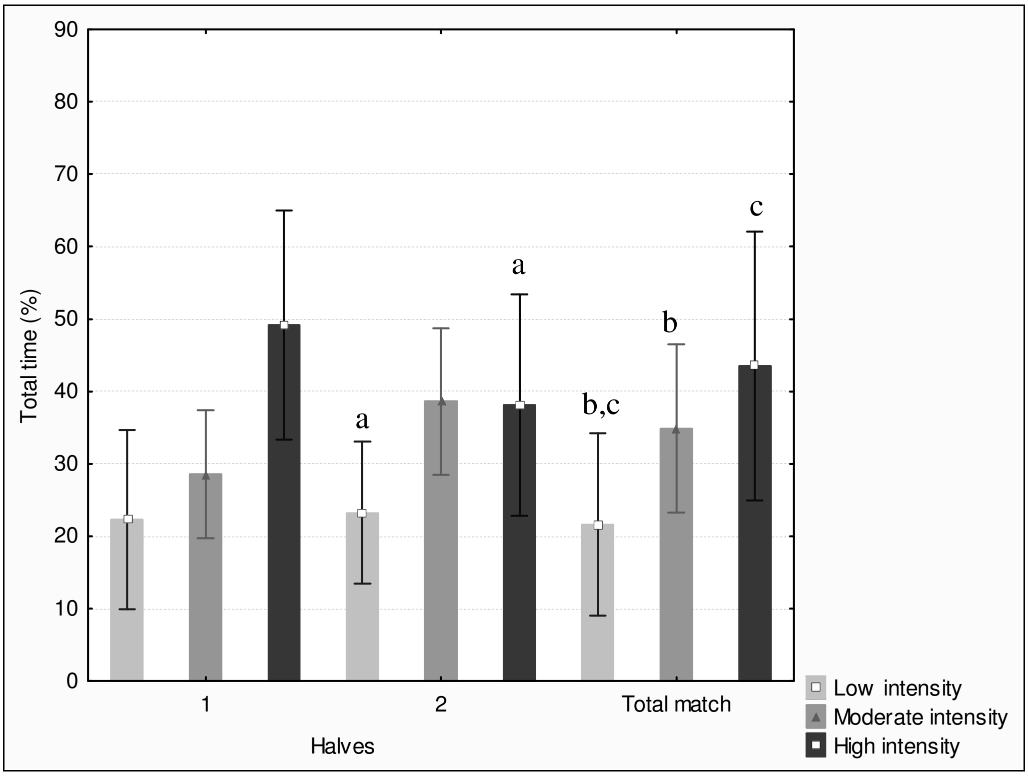

FIGURE 1: Time spent in the different intensity zones during the entire match and different halves.

When the same letter appears above two or more intensity zones, a significant difference ($p<0.05$) occurred.

TABLE 4. Descriptive statistics of the different intensity zones identified for the different matches

Variable	Low	Moderate	High
Total time spent in the intensity zones during 1st half (min:sec)	08:12±09:00	10:12±06:35	16:50±06:44
Total time spent in the intensity zones during 2nd half (min:sec)	08:03±06:45	13:22±06:44	13:00±09:48
Total time spent in the intensity zones during entire match (min:sec)	15:06±14:44	24:05±13:13	29:38±20:35
Duration of different intensity bouts during 1st half (min:sec)	00:33±00:28	00:27±00:13	01:38±02:04
Duration of different intensity bouts during 2nd half (min:sec)	00:26±00:17	00:29±00:15	00:55±00:56
Duration of different intensity bouts during whole match (min:sec)	00:29±00:23	00:29±00:15	01:17±01:40

Hr_{max} - heart rate maximum

DISCUSSION

The use of time-motion, blood lactate and heart rate analyses for the determination of rugby match demands have been questioned due to the limitations that have been identified. Hence the purpose of this study was to determine the intensities of tertiary institution rugby union games by making use of a different method which uses the players' in-game and graded maximal test heart rates as well as other respiratory-related variables.

The results of the study firstly showed that the last-mentioned method can be used to determine the intensities of tertiary institution rugby union games. From these results it is also apparent that the players spent more time in the high-intensity zone during match play compared to previous time-motion analyses studies (5,6,9,16,17), which was unexpected. There were significant differences between the percentage of time players spent in the low and high-intensity zones during the second halves and during the match as a whole respectively. Significant differences were, however, observed when the percentage of time spent in the low and moderate-intensity zones during the entire match were compared. The study did therefore not succeed in showing that tertiary institution rugby games will be categorized by significantly more low and moderate-intensity activities compared to high-intensity activities.

No other studies have been conducted that had used heart rates and graded maximal test values to determine the intensities of team sport participants during match play. It is therefore not possible to directly compare the results of this study with similar studies. However, several studies have used time-motion, blood lactate and heart rate analyses to determine rugby game intensities (5,6,9,16,17). However, these studies were performed on professional or elite rugby players and not on tertiary institution rugby players, which may make comparisons between the results of this study and those of other studies difficult. Still, comparisons between this and another study (5) revealed that the tertiary institution rugby players in this study spent more of the total game time in the high-intensity heart rate zone (43.6% *versus* 58.5%). Also, compared to players in other studies (5,9,17), where the mean duration of high intensity bouts (work) was seldom higher than 6 seconds, with a few bouts that surpassed 12 seconds, the players in the current study showed a mean high-intensity bout duration of 87 seconds.

Three possible reasons can be provided for the huge disparity that exists between the duration of time spent in the high-intensity heart rate zone by players in this study compared to players of previous studies. Firstly, previous studies only categorized activities into high and low-intensity activities, with no moderate-intensity activities noted. This study, on the other hand, made use of a low, moderate and high-intensity categorization. The difference in categorization between this and other studies may have influenced the distribution of intensity zones very differently from that which was reported previously. Secondly, the use of heart rates to categorize the high-intensity zone allows researchers to get a more accurate reflection of the real physical exertion players perform when executing certain tasks. In most cases the heart rates will take a few seconds to decrease back to the moderate-intensity range, which will probably increase the period players spent in the high-intensity heart rate zone. In comparison, previous studies used time-motion analyses where high-intensity activities were timed as it took place and the time watch stopped as soon as the activity reached its end. This will definitely lead to shorter time periods in the high-intensity zone when compared to a study where the heart rate-related analysing method was used.

Thirdly, in cases where researchers used players' data collected before 2000 and 2007 (9,17), when certain rule changes had not yet taken place, the relevance of these results on today's rugby players can be questioned. With regard to the effect of rule changes on the demands of a rugby union game, Williams et al. (22) indicated that rule changes led to a significant increase in ball-in-play time, which will directly influence the game demands by increasing it. This finding was further substantiated by Van den Berg and Malan (21) who discovered a significant decrease in the number of scrums and line-outs as well as a significant increase in the number of tackles made, meters gained and rucks won during the Super 14 Tournament of 2008 when compared with the values of previous years. They attributed these results to, amongst other things, the rule changes introduced in 2008. All of these findings suggest that players would spend more time in the high-intensity zone due to the rule changes that had been introduced.

With regard to the intensity zone heart rates identified by means of the standard incremental oxygen uptake test results, the mean heart rates for categorizing the moderate and high-intensity zones were calculated to be 82.0% and 91.2% of the maximum heart rate respectively. These findings are not in agreement with the proposed heart rate-intensity guidelines of 60% and 80% of the maximum heart rate for the corresponding intensity zones (2). From these results it is clear that general heart rate-intensity guidelines cannot be accurately applied to team sport participants, such as rugby players. Individualized, physiologically determined and sport specific heart rate-intensity guidelines would therefore be much more accurate and relevant for use among team sport participants.

In summary, to date, research work with regard to the use of more accurate and relevant methods to determine the intensities of team sports is insufficient. The use of more complex training methods among rugby players, as well as the fact that various rule changes have been implemented since 2000, may lead to the emergence of new trends and activity profiles among rugby players during match play. Hence scientists need to investigate new ways of analysing and conceptualizing the on-field activities of team sport participants such as rugby players. This is the first study that has attempted to address this need.

However, the results of the present study must be interpreted with caution, since the results are only applicable to tertiary institution rugby games. The accuracy of this method to determine the demands of rugby union games should thus be measured and tested through more elaborate studies on rugby players of different participation levels. Furthermore, seen from a physiological viewpoint, it should be noted that the standard incremental treadmill test may not be the most suitable method for determining the heart rate-intensity zones for use in analysing the rugby match demands. Rugby games consist of running different distances, pivoting and making frequent changes in direction while constantly accelerating and decelerating. The movements during the treadmill running test are continuous, forward running at constant speeds. The muscle recruitment patterns and energy demands during a rugby match will therefore probably be different from those of the treadmill test. This notion was also substantiated by the difference in the average maximal heart rate values observed between the standard incremental treadmill test and the rugby games. However, until now no other method or test has been designed to determine the heart rate-intensity zones of athletes. This is an aspect researchers need to consider when making use of the proposed method to determine team sport participants' game intensities.

PRACTICAL APPLICATIONS

The use of in-game and graded maximal test heart rates as well as other respiratory-related variables will enable sport scientists and other sport-related professionals to draw more valid conclusions with regard to the demands of a team sport such as rugby union. What the results of this method also show is that sport scientists and conditioning coaches should construct training programs to concentrate primarily on high-intensity activities, which are fuelled by the anaerobic glycolytic energy system. On the other hand, the importance of the aerobic energy system should not be overlooked, since the body primarily depends on aerobic energy during the recovery period between high-intensity bouts.

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CHAPTER 4

4 THE USE OF HEART RATES AND GRADED MAXIMAL TEST VALUES TO DETERMINE POSITIONAL DIFFERENCES IN RUGBY UNION GAME INTENSITIES

The use of heart rates and graded maximal test values for determining positional differences in rugby union game intensities

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The use of heart rates and graded maximal test values for determining positional differences in rugby union game intensities

The determination of positional differences in Rugby Union Game Intensities

Key words: physiology, thresholds, game analysis, oxygen uptake, intensities, $\dot{V}O_{2max}$

ABSTRACT

The purpose of this study was to determine the positional differences in tertiary institution rugby game intensities, using heart rates and graded maximal test values. In the weeks between three rugby matches ten forwards and eleven backs performed a standard incremental maximal oxygen uptake ($\dot{V}O_{2max}$) test to the point of exhaustion. The test was used for determining two ventilatory threshold points by which the low, moderate and high-intensity heart rate zones were categorized for each of the players. The telemetry heart rate values recorded during each of the matches revealed that forwards spent significantly more ($P < 0.05$) time in the high-intensity zone compared to the backs (54.6% vs. 32.7), whereas the backs spent significantly more time in the low-intensity zone during the match compared to the forwards (34.2% vs. 11.3%). In conclusion, this is the first study to make use of heart rate and graded maximal test values to show that significant differences exist with regard to the game time spent in the different heart rate intensity zones between rugby union forwards and backs.

The use of heart rates and graded maximal test values for determining positional differences in rugby union game intensities

Introduction

In order to construct sport and position specific training regimens for players, the physiological demands players of different positions experience during match play have to be available (Duthie, Pyne & Hooper, 2003a). The diverse nature of movement patterns and frequent bouts of physical contact in rugby games make the physiological demands of rugby union much more complex to analyse compared to individual sports (Duthie *et al.*, 2003a). Numerous studies have determined the amount of work and work intensities of different rugby playing positions during match play by applying several methods (Deutsch, Maw, Jenkins & Reaburn, 1998; Duthie, Pyne & Hooper, 2005; Deutsch, Kearney & Rehrer, 2007; Roberts, Trewartha, Higgitt, El-Abd & Stokes, 2008). One of these methods is time-motion analysis (Deutsch *et al.*, 1998; Duthie *et al.*, 2005; Deutsch *et al.*, 2007; Roberts *et al.*, 2008) in conjunction with heart rate recording and analysis (Deutsch *et al.,* 1998) as well as blood lactate monitoring (Deutsch *et al.,* 1998).

Before the match analyses can take place, the players need to be divided into groups in accordance with the on-field requirements (Deutsch *et al.,* 1998). Four positional groups are usually identified, namely front row forwards (prop and locks), back row forwards (flanker, eighth man and hooker), inside backs (fly halves and centres) and outside backs (wings and full backs) (Roberts *et al.,* 2008). Time-motion analysis quantifies the movements of players during match play by grouping the movement patterns into categories according to their intensities (Duthie *et al.,* 2003a). These movements can generally be divided into low-intensity activities (standing, walking and jogging) and high-intensity activities (cruising, sprinting and static exertion such as rucking, mauling, etc.) (Deutsch *et al.,* 1998; Duthie *et al.,* 2005; Roberts *et al.,* 2008). Although these studies provide the reader with valuable information with regard to the differences in match play intensities, certain discrepancies exist when making use of time-motion analysis alone. In this regard, Duthie, Pyne and Hooper (2003b), for example, investigated the reliability of time-motion analysis and concluded that video-based time-motion analysis is only moderately reliable as an evaluation tool for examining movement patterns.

Furthermore, Duthie *et al.* (2005) questioned the accuracy of time-motion analysis due to the lack of direct measurements of especially static exertion activities where players do not necessarily exert themselves maximally. Despite of this problem rucks, mauls and scrums are usually categorized as high-intensity movements. It is against this background that researchers have proposed the measurement and use of heart rates and blood lactate values in an attempt to strengthen the accuracy of the time-motion analyses' results (Deutsch *et al.* 1998).

However, as with the use of time-motion analysis, there are certain shortcomings that need to be addressed when both blood lactate and heart rate analyses are used. The collection of blood samples for blood lactate analysis is dictated by stoppages in match play (Duthie *et al.,* 2003a). In instances where the time period that elapses before blood lactate samples are taken after the execution of high-intensity activities are too long, the blood lactate will be metabolised and will not give a true reflection of the rugby game demands (Duthie *et al.,* 2003a). The use of heart rate guidelines alone may also lead to errors in the estimation of exercise intensities and rugby match demands due to individual differences in fitness levels and variations in exercise economy (Achten & Jeukendrup, 2003).

In an attempt to find and develop a more accurate method of determining the match play demands of different playing positions in rugby, the researcher's attention was drawn to a method where both the heart rate values and graded maximal test gas analyses values of athletes are used. The direct measurement of oxygen uptake ($\dot{V}O_2$) by indirect calorimetry and specifically by open-circuit spirometry during a graded maximal test allows researchers to identify two physiological gas exchange points, namely the aerobic threshold/ventilatory threshold (VT_1) and anaerobic threshold/respiratory compensation point (RCP) (Foster & Cotter, 2006). The heart rates that correspond to the exercise intensities below the VT_1 (low-intensity), between VT_1 and RCP (medium intensity) and above the RCP (high intensity) are then determined to classify the different exercise intensity heart rates (Foster & Cotter, 2006). The identified individual exercise intensity heart rates are then used to categorize and determine the intensities of different activities and movements during match play. To date no researchers have attempted to use this method for determining the match play intensities of team sports. To date, the last-mentioned method has only been used to quantify the competition demands of individual sports such as cross-country running (Esteve-Lanao, San Juan, Earnest, Foster & Lucia, 2005), cross-country skiing (Seiler & Kjerland, 2006) and road cycling (Lucia, Hoyos & Chicharro,1999; Rodriguez-Marroyo, Garcia-Lopez, Juneau & Villa, 2009).

Coaches and sport scientists will only be able to condition players specifically for the position-specific demands of rugby union match play if the amount of time the players need to perform at certain intensities during the rugby games are available (Duthie *et al.,* 2003a). It is against this background and the lack of research concerning the use of a more accurate and reliable method for determining the position specific demands of rugby union match play that this study was undertaken. Therefore the purpose of this study was to determine the positional differences in tertiary institution rugby game intensities, using heart rates and graded maximal test values.

Method

Participants

Twenty-one male rugby union players from the first and second rugby teams of the North-West University (Potchefstroom Campus – South Africa) were selected for this study. The characteristics of the subjects, who participated in the study, are presented in Table I. For the players' data to be included in the study, they had to spend at least 50% (one half) of the game on the field; they had to complete a standard incremental running test to the point of exhaustion at least two weeks before or after the game and they had to be injury free at the time of testing. All players not adhering to these criteria were excluded from the study. The players were divided into two positional groups, namely forwards (n=10) that consisted of the eight front line players and backs (n=11) that consisted of the seven back line players. The players' data were collected during three separate matches, with between four and nine players monitored during each match. The objectives of the study were explained to the players, after which they completed an informed consent form. Approval for the research was granted by the Ethics Committee of the North-West University.

TABLE I. Physical characteristics of participants*

Parameters	Subjects (*n = 21)*	Forwards (n = 10)	Backs (n = 11)
Age (y)	22.2±1.2	22.2±1.5	22.2±0.8
Body stature (cm)	182.3±7.1	185.9±7.9	179.1±4.7
Body mass (kg)	97.6±12.9	108.1±10.5	88.0±5.0

*Values are mean±*SD*.

Procedures

Standard incremental maximal oxygen uptake ($\dot{V}O_{2max}$) test to the point of exhaustion. A standard incremental maximal oxygen uptake ($\dot{V}O_{2max}$) test was conducted by means of open-circuit spirometry. Each of the players performed the standard incremental test to the point of exhaustion on a Woodway Pro XL treadmill (Woodway, W229 N591, Foster Ct, Waukesha, WI). Prior to each test the players warmed up on the treadmill for 5 min at a speed of 10 km·h^{-1} after which the speed was increased to 15 km·h^{-1} for a duration of 10 s. Static stretches, which involved the following body parts, were then executed for a duration of 20 s per stretch: shoulders, arms, chest, the upper as well as the lower legs. At commencement of the standard incremental test the first 2 minutes were performed at 8 km·h^{-1}, after which the treadmill speed was increased to 10 km h^{-1}, and by 1 km h^{-1} every minute after the first two minutes. Expired air was continuously sampled by an Oxycon Pro static ergospirometry system (Jaeger Oxycon Pro, Viasys, 22745, Savi Ranch Parkway, Yorba Linda, CA, USA) and the rate of oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), minute ventilation ($\dot{V}_E$) and the respiratory exchange ratio (RER) were calculated every 5 s by an on-line computer system. The Oxycon Pro was calibrated in accordance with the manufacturer's specifications at the beginning of each test day. The test was stopped if the player indicated that it must be stopped or if the criteria for reaching the $\dot{V}O_{2max}$ value was achieved (e.g. a respiratory exchange ratio-value higher that 1.10 at test termination; oxygen consumption ceases to rise and reaches a plateau or begins to fall even though the work rate continues to increase or the maximal age specific heart rate is reached) (Davis, 2006; McArdle, Katch & Katch, 2001). Throughout the test, heart rate was recorded for each 5 s period by means of a Fix Polar T61 Heart Rate Transmitter Belt (Polar electro OY, Kempele, Finland).

Ventilatory threshold point (VT_1) and respiratory compensation point (RCP). Two physiological gas exchange points were identified. The VT_1 was determined using the criteria of an increase in $\dot{V}_E/\dot{V}O_2$ with no increase in $\dot{V}_E/\dot{V}CO_2$ and departure from the linearity of $\dot{V}_E$ (Chicharro, Hoyos & Lucia, 2000). The RCP was taken as the point that corresponds to an increase in both $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$ (Chicharro *et al.,* 2000). Two independent experienced scientists visually detected VT_1 and RCP. The different gas exchange phases were used for determining the heart rates that correspond to the three exercise intensities (Chicharro *et al.,* 2000). Heart rates that corresponded to the exercise intensities below VT_1 were classified as zone 1 (low-intensity) heart rates; heart rates that corresponded to the exercise intensities between VT_1 and RCP were classified as zone 2 (moderate-intensity) heart rates and heart rates that corresponded to the exercise intensities above RCP were classified as zone 3 (high-intensity) heart rates.

Rugby game heart rates. The heart rates of players were recorded at 4 s intervals during matches using the Hosand TM Pro telemetry heart rate monitoring system (Hosand Technologies Srl, Verbania, Italy). An electrode belt was strapped around the chest at the lower sternum of each player before the start of each match. The heart rate signal was then downloaded to a PC during each of the matches.

Statistical analysis

The Statistical Consultation Service of the North-West University determined the statistical methods and procedures for the analyses of the research data. The Statistical Data Processing package (Statsoft Inc., 2009) of the North-West University was used to process the collected data. Firstly, the heart rates each player attained during the games were categorized into the three intensity zones (low, moderate and high) according to the results of each of the standard incremental tests executed during the periods before or after the games had taken place. The time spent in the different zones was then expressed as a percentage of the total game time (excluding the time before the games and half time). Secondly, the descriptive statistics (averages, minimum, maximum and standard deviation values) were calculated for each variable. Lastly, an independent t-test was done to determine whether any significant differences occurred between the two positional groups with regard to the rugby game intensities. The level of significance for the t-test was set at $P < 0.05$.

Results

Standard incremental test values

The results obtained from the standard incremental test are presented in Table II. The average $\dot{V}O_{2max}$ for the forwards and the backs were 41.96±5.04 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ and 43.41±8.30 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ respectively with the average maximum heart rate values being 187±7.76 bpm and 183±6.10 bpm respectively. The first gas exchange point, the VT_1, occurred at a higher average heart rate for the forwards than the backs (156 *versus* 150 bpm). This point occurred at 83% and 81% of the maximum heart rate (% HR_{max}) respectively. The RCP on the other hand occurred at an average heart of 173 bpm (92% HR_{max}) for the forwards and 165 bpm (90% HR_{max}) for the backs. The heart rate zones for the forwards were determined to be: 146-155 bpm, 156-173 bpm and 174-187 bpm for the low, moderate and high-intensity zones respectively. In comparison the backs' average heart rates for the intensity zones were generally lower at 136-149 bpm, 150-165 bpm and 166-183 bpm respectively.

Match analyses

Table III shows the descriptive statistics for all the match analyses-related measurements. The average match heart rate for the forwards was 173 bpm, which falls within the moderate-intensity zone when categorized according to the heart rates in Table II. In comparison, the average heart rate for the backs was 158 bpm, which can also be classified as a moderate-intensity heart rate. On average, the forwards spent more time on the field compared to the backs (58min:34s *versus* 54min:24s).

TABLE II. Standard incremental test-related measurements of participants

Parameters	Subjects (*n = 21)*	Forwards (n = 10)	Backs (n = 11)
$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	42.70±6.8	41.96±5.04	43.41±8.30
HR_{max} (bpm)	185.10±7.0	187.00±7.76	183.36±6.10
VT_1 (% $\dot{V}O_{2max}$)	70.70±8.6	72.46±6.33	69.33±10.14
VT_1 (ml·kg^{-1}·min^{-1})	29.50±6.0	28.93±5.17	30.03±6.78
VT_1 (RER)	0.98±0.1	0.97±0.07	0.98±0.05
VT_1 (bpm)	153.00±12.0	155.60±12.51	149.83±11.48
VT_1 (% HR_{max})	82.70±4.2	83.11±3.93	81.01±4.34
RCP (% $\dot{V}O_{2max}$)	85.40±5.7	86.70±3.24	84.30±7.32
RCP (ml·kg^{-1}·min^{-1})	36.40±6.0	36.36±4.46	36.52±7.35
RCP (RER)	1.06±0.1	1.06±0.06	1.07±0.04
RCP (bpm)	169.00±10.9	172.90±11.63	165.36±9.51
RCP (% HR_{max})	91.40±3.4	92.40±3.01	90.15±3.43
Low-intensity HR zone (bpm) (% HR_{max})	141-152 (76.2-82.0)	146-155 (78.0-83.0)	136-149 (74.1-80.9)
Moderate-intensity HR zone (bpm) (% HR_{max})	153-169 (82.7-91.4)	156-173 (83.1-92.4)	150-165 (81.0-90.2)
High-intensity HR zone (bpm) (% HR_{max})	170-185 (91.9-100.0)	174-187 (92.5-100.0)	166-183 (90.3-100.0)

$\dot{V}O_{2max}$ - maximum oxygen uptake; HR_{max} - maximum heart rate; VT_1 (% $\dot{V}O_{2max}$) - ventilatory threshold expressed as a percentage of the maximum oxygen uptake; VT_1 (ml·kg^{-1}·min^{-1}) - oxygen uptake at the ventilatory threshold; VT_1 (RER) - respiratory exchange ratio at ventilatory threshold; VT_1 (bpm) - heart rate at the ventilatory threshold; VT_1 (% HR_{max}) - ventilatory threshold expressed as a percentage of the maximum heart rate; RCP (% $\dot{V}O_{2max}$) - respiratory compensation point expressed as a percentage of the maximum oxygen uptake; RCP (ml·kg^{-1}·min^{-1}) - oxygen uptake at the respiratory compensation point; RCP (RER) - respiratory exchange ratio at the respiratory compensation point; RCP (bpm) - heart rate at the respiratory compensation point; RCP (% HR_{max}) - respiratory compensation point expressed as a percentage of the maximum heart rate; %HR_{max} - percentage of the maximum heart rate.

TABLE III: Descriptive statistics for all the match analyses-related variables

Variable	Mean	Forwards (n = 10)	Backs (n = 11)
HR_{max} (bpm)	192.2±8.8	196.9±3.45	188.0±10.18
HR_{avg} (bpm)	165.0±12.3	173.0±5.78	157.7±12.21
Game time (min:s)	56:23±16:55	58:34±15:18	54:24±18:46

HR_{max} - maximum heart rate; HR_{avg} - average heart rate.

Figure 1 shows the mean time expressed as a percentage of the total game time spent in the different intensity zones during the first and second halves, as well as during the entire match for each of the positional groups. From Figure 1 it is evident that players spent the majority of time during matches in the high-intensity zone. Comparatively, the backs spent significantly ($P < 0.05$) more time in the low-intensity zone during the first halves, comprising 34.5% of the time, with the forwards that spent only 8.6% of the time in this intensity zone during the first halves. Likewise, the backs also spent significantly more time than the forwards in the low-intensity zone during the second halves (33.8% *versus* 13.8%). When looking at the match as a whole, the backs spent 34.2% of the total time in the low-intensity zone, whereas the forwards spent only 11.3% of the time in this intensity zone. These differences were, however, significant when comparisons were drawn. In contrast, the forwards spent significantly more of the total match time in the high-intensity zone (54.6%) than the backs (32.7%).

The duration of time the two positional groups spent in each of the intensity zones are presented in Table IV. The mean total time spent in the different intensity zones by the forwards during the matches are as follows: 07min:26s, 22min:56s and 37min:23s for the low, moderate and high-intensity zones respectively. On the other hand, the backs spent more time than the forwards in the low (24min:04s) and moderate (25min:25s) intensity zones and less time (20min:36s) in the high-intensity zone. The mean duration of high-intensity bouts also lasted longer for the forwards than for the backs (1min:51s *versus* 38s) when the matches were analysed as a whole. Consequently the mean duration of the low and moderate-intensity bouts for the backs were considerably longer than those of the forwards (43s and 33s *versus* 17s and 26s).

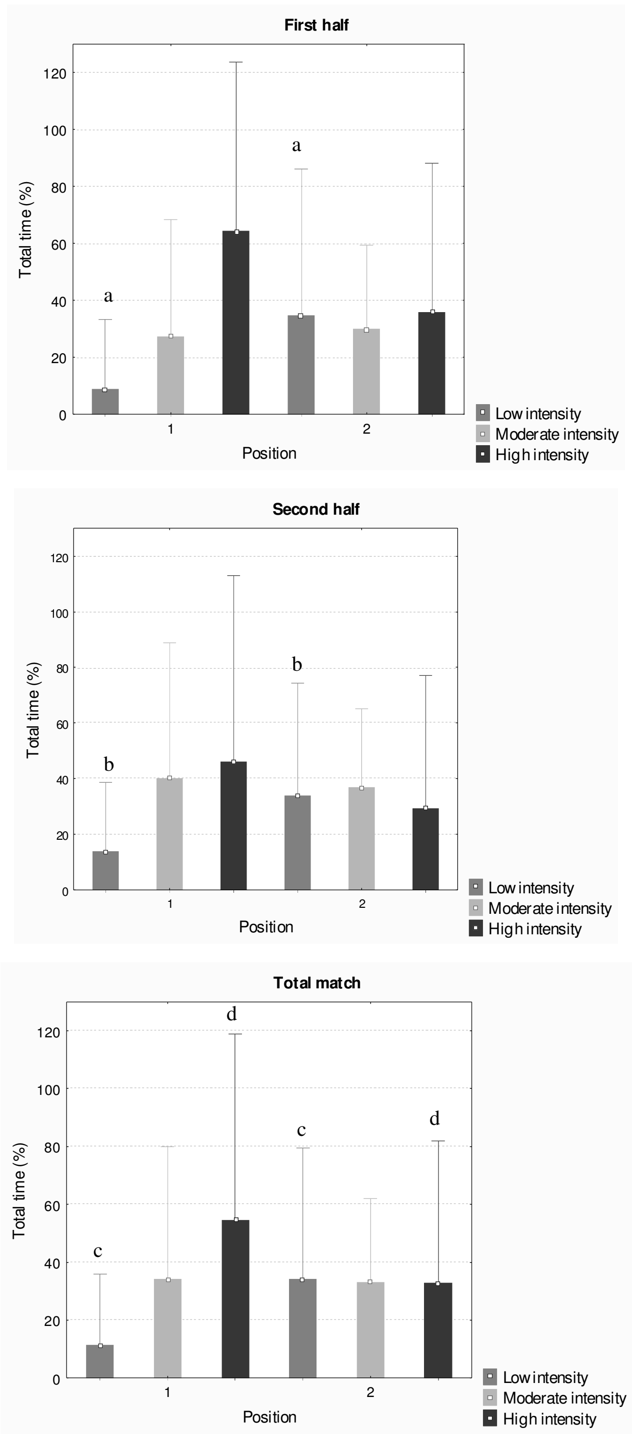

FIGURE 1: Time spent in the different intensity zones during the entire match and different halves for each position

1 – Forwards; 2 – Backs. When the same letter appears above two or more intensity zones, a significant difference ($P < 0.05$) was present.

TABLE VI. Descriptive statistics of the different intensity zones identified for the different matches

Variable	Low	Moderate	High
		Forwards	
Total time spent in the intensity zones during 1st half (min:s)	02:56±04:33	09:04±07:17	21:11±10:36
Total time spent in the intensity zones during 2nd half (min:s)	04:58±04:21	14:26±08:34	16:08±11:07
Total time spent in the intensity zones during entire match (min:s)	07:26±08:56	22:56±15:38	37:23±22:08
Duration of different intensity bouts during 1st half (min:s)	00:16±00:13	00:24±00:13	02:30±02:49
Duration of different intensity bouts during 2nd half (min:s)	00:18±00:11	00:27±00:12	01:09±01:13
Duration of different intensity bouts during entire match (min:s)	00:17±00:11	00:26±00:14	01:51±02:10
		Backs	
Total time spent in the intensity zones during 1st half (min:s)	12:53±09:35	11:12±06:09	12:57±09:01
Total time spent in the intensity zones during 2nd half (min:s)	11:31±07:31	12:09±04:06	09:28±07:11
Total time spent in the intensity zones during entire match (min:s)	24:04±15:41	25:25±11:01	20:36±15:44
Duration of different intensity bouts during 1st half (min:s)	00:47±00:30	00:30±00:13	00:52±00:29
Duration of different intensity bouts during 2nd half (min:s)	00:35±00:18	00:30±00:18	00:39±00:21
Duration of different intensity bouts during entire match (min:s)	00:43±00:26	00:33±00:17	00:38±00:18

HR_{max} – maximum heart rate

Discussion

The purpose of the current study was to establish significant differences with regard to intensities during tertiary institution rugby union games between forwards and backs by making use of heart rate and graded maximal test values of the players. The main finding of this study was that the forwards spent significantly more time in the high-intensity zone compared to the backs that spent significantly more game time in the low-intensity zone during the first and second halves as well as during the match as a whole. Furthermore, the use of heart rate and graded maximal test values can be regarded as a legitimate method for determining positional differences in intensities between forwards and backs during tertiary institution rugby union match play.

Currently this is the only study to use heart rate and graded maximal test values for determining the intensities of team sport participants during match play. It is therefore not possible to draw direct comparisons between the findings of this study and those of similar studies. Nonetheless, findings of studies which used time-motion, blood lactate and heart rate analyses (Deutsch *et al.*, 1998; Duthie *et al.*, 2005; Deutsch *et al.*, 2007; Roberts *et al.*, 2008) are similar to those of the present study. The forwards spent significantly more time in the high-intensity zone during the entire match compared to the backs, whereas the backs spent significantly more time in the low-intensity zone during the first and second halves as well as during the match as a whole, when compared to the forwards. This was expected due to the greater involvement of forwards in static exertion type of activities (Deutsch *et al.*, 1998; Duthie *et al.*, 2005; Deutsch *et al.*, 2007; Roberts *et al.*, 2008). According to Duthie *et al.* (2005), backs are not so active compared to forwards when competing for the ball due to their lesser involvement in the game. High-intensity activities are primarily dependant on the anaerobic glycolytic energy system for energy delivery (Deutsch *et al.*, 2007). The forwards will therefore depend more on the named energy system compared to the backs. On the other hand, the backs will depend more on the aerobic energy system due to the significantly higher amount of game time spent in the moderate and low-intensity zones compared to the forwards.

The amount of time both positional groups spent in the high-intensity zone during match play was much higher than the previously reported values of time-motion analyses studies. In this regard the forwards and backs spent 37min:23s and

20min:36s respectively in the high-intensity zone compared to 9min:09s and 3min:04s reported by Roberts *et al.* (2008). Deutch *et al.* (1998) also found that forwards spent more total work (11.2 min) in the high-intensity zone than the backs (3.5 min). Furthermore, the mean duration of high-intensity activities for both the forwards (111 s) and backs (38 s) were considerably longer than the time periods of 4.1 s and 2.3 s found by Roberts *et al.* (2008). With regard to the percentage of game time spent in each intensity zone in this study, forwards spent 54.6% of the total game time in the high-intensity zone, whereas the backs only spent 32.7% of the total game time in the high-intensity zone. Deutch *et al.* (2007), on the other hand, found that the forwards spent 12-13% of the total game time in the high-intensity zone compared to the backs that only spent 4.5% of the total game time in the high-intensity zone. These findings are noteworthy as it indicates that the demands placed on the tertiary institution players during match play were much higher and for longer periods of time than were previously reported by other researchers (Deutsch *et al*., 1998; Deutsch *et al*., 2007; Roberts *et al.,* 2008). These researchers used time-motion analyses and not the heart rate values of the players to quantify the demands of rugby match play. Moreover, these researchers only categorised the intensity zones into low and high-intensity zones, compared to the categorisation into low, moderate and high-intensity zones used in this study. The last-mentioned facts may in part explain the differences in the duration of intensity zones between this and other studies.

Although studies conducted before 2008 have contributed towards the understanding of the demands of rugby union, the relevance of these results on today's rugby players can be questioned due to rule changes. The International Rugby Board (IRB) introduced a number of rule changes since 1999 to improve the safety and competitiveness of rugby union. These rule changes resulted in more ball in game time, an increase in the number of tackles made, meters gained and rucks won during matches compared to the matches prior to 2008 (van den Berg & Malan, 2010). The changes referred to will definitely also increase the intensity and duration of high-intensity activities, which may help to explain the dissimilarities between the amount of time spent in the different intensity zones between this and other studies.

With reference to the heart rates at which the moderate and high-intensity zones were identified for each of the positional groups, the heart rate zones generally started at a higher percentage of the maximum heart rate for the forwards than backs. The heart rates at which the different intensity zones were identified were dictated by the VT_1 and RCP obtained during the incremental oxygen uptake test. These ventilatory thresholds, especially the RCP, are good indicators of an athlete's potential for prolonged physical activity (Chicharro *et al.,* 2000; Lucia, Hoyos & Chicharro, 2001). The higher threshold heart rates of the forwards may be an indication of a better conditioning level among this positional group compared to the backs. Another important finding to consider is that the heart rate intensity zones identified for the rugby players in this study were much higher than the theoretically prescribed heart rate guidelines of Burke (1998) (moderate: 82.7% *versus* 60% of the maximal heart rate; high: 91.9% *versus* 80% of the maximal heart rate). This finding stresses the importance of individualised and physiologically determined heart rate guidelines opposed to general theoretically determined heart rate guidelines.

Conclusion

This study is the first to have used heart rate and graded maximal test values to establish differences with regard to intensities during tertiary institution rugby games between forwards and backs. The first conclusion that can therefore be drawn from the study is that the method that applies heart rate and graded maximal test values for determining game intensities of rugby union forwards and backs is valid. By applying this method it was found that forwards spent significantly more total match time in the high-intensity zone, with longer periods of high-intensity bouts compared to the backs that spent significantly more total game time in the low-intensity zone during the matches. Therefore sport scientists and conditioning coaches should construct different training programs for the two positional groups, concentrating more on frequent high-intensity activities lasting more or less 40 s for the backs and more or less 111 s for the forwards. The backs do, however, need to be exposed to more moderate and low-intensity work during training compared to forwards. Although these results add valuable understanding towards the demands of rugby union games, one should be careful to generalise these results to all levels of competition in rugby union.

Further research should be conducted to determine the rugby union game demands for all levels of participation, as well as to determine match demand differences between the two positional groups. It should also be noted that the standard incremental treadmill test is a linear test during which there are no changes in direction or sudden bursts of acceleration and deceleration. Furthermore, a motorised treadmill which generates the speed at which the player must run is used during the test. All of these mentioned facts may lead to different muscle recruitment patterns and energy demands when compared to the actual match play situation. This notion was substantiated by the average maximal heart rate differences found between the treadmill test and the actual match play. As such, it can be recommended that further studies should focus on developing a more rugby specific incremental test for determining the two ventilatory threshold points for categorisation of the different heart rate intensity zones.

Another point to consider is the small group sizes of this study, which may have caused outliers to have influenced the mean values of the respective heart rate intensity zones more than would have been the case with larger group sizes. Therefore the suitability of this new method for determining the match play intensity differences between rugby union forwards and backs should be tested by making use of a much larger sample of rugby players. Despite all of these shortcomings this study forms a basis from which other researchers can plan and conduct studies of this nature.

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CHAPTER 5

5 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5. SUMMARY

The purpose of this study was twofold – firstly, to determine the intensities of tertiary institution rugby union games using heart rate and graded maximal test values and secondly, to determine positional differences in tertiary institution rugby union game intensities using heart rates and graded maximal test values. Chapter 1 provided a brief problem statement that culminated in the research questions of the study, the objectives and the related hypotheses as well as the structure of this dissertation.

Chapter 2 consisted of a literature overview titled "The application of different methods to determine the game intensities of rugby union". The purpose of this chapter was firstly to provide the reader with a brief scientific background concerning the rules and characteristics of a typical rugby union match, the different methods that have been applied in the past to determine the match demands of rugby union players as well as the results of rugby union match analysing-related studies, the shortcomings of previous match analysing methods and the possibility of applying an alternative method for analysing rugby union game intensities.

In general the literature suggests that rugby union players spent most of the time in the moderate to low-intensity zone with short bouts of high-intensity activities. Furthermore, literature suggests that forwards spend significantly more time in the high-intensity zone when compared the backs due to the high frequency of static exertion type of activities.

On the other hand backs spend significantly more time in low and moderate-intensity activities when compared to forwards.

Chapter 3 comprises of the first article which was compiled in accordance with the guidelines of The Journal Strength and Conditioning Research and entitled: "The use of heart rates and graded maximal test values to determine rugby union game intensities". The purpose of this article was to determine the intensities of tertiary institution rugby union games, using heart rates and graded maximal test values. Firstly the study succeeded in showing that the use of heart rates and graded maximal test values is a legitimate method for determining tertiary institution rugby game intensities. Secondly, the results showed that tertiary institution rugby players spent significantly ($p < 0.05$) more time in the high-intensity zone when compared to the low and moderate-intensity zones, when the match was considered as a whole. The results of the current study contradicted the results of previous studies which found that players spent most of the total game time in the low and moderate-intensity zones. Also, players spent significantly more time ($p < 0.05$) in the high-intensity zone when compared to the low-intensity zone during the second halves. During the first halves, however, there were no significant differences between any of the intensity zones. In addition, the duration of high-intensity bouts was much longer in the current study compared to those of previous studies, while the duration of low-intensity bouts was much shorter than previously reported.

Chapter 4 consisted of the second article which was compiled in accordance with the guidelines of The Journal of Sports Science and titled: "The use of heart rates and graded maximal test values to determine positional differences in rugby union game intensities". The purpose of this study was to determine the positional differences in tertiary institution rugby game intensities, using heart rates and graded maximal test values. It was shown that the heart rate and graded maximal test value method is a legitimate method for determining the positional differences in tertiary institution rugby game intensities. Furthermore, the results of this article suggested that the backs spent significantly ($p < 0.05$) more time in the low-intensity zone during the first and second halves when compared to the forwards. When the match as a whole was considered the results suggested that the forwards spent significantly ($p < 0.05$) more time in the high-intensity zone compared to backs, with the backs alternatively spending significantly more time in the low-intensity zone. Also, the duration of high-intensity bouts was longer for the forwards than for the backs (54.6% *versus* 32.7%), whereas the duration of the low-intensity bouts were longer for the backs than for the forwards (34.2% *versus* 11.3%).

6. CONCLUSIONS

The conclusions drawn from this research are presented in accordance with the set hypotheses (Chapter 1):

Hypothesis 1: *When heart rates and graded maximal test values are used for determining the game intensities during tertiary institution rugby games, it will be found that significantly more game time will be spent in the low and moderate heart rate zones than in high-intensity heart rate zone.*

Hypothesis 1 is rejected due to the conclusion that players spent significantly more total game time in the high-intensity heart rate zone compared to the low-intensity heart rate zone when heart rate and graded maximal test values were used for determining the intensities of tertiary institution rugby union matches.

Hypothesis 2: *When heart rates and graded maximal test values are used for determining the game intensities during tertiary institution rugby games, it will be found that forwards will spend significantly more game time in the high-intensity heart rate zone compared to the backs, whereas the backs will spend significantly more game time in the low and moderate-intensity heart rate zones compared to the forwards.*

Hypothesis 2 is accepted, since the results of this study showed that forwards spent significantly more total game time in the high-intensity heart rate zone than the backs when heart rates and graded maximal test values were used for determining tertiary institution rugby game intensities. Also, results showed that the backs spent significantly more time in the low-intensity heart rate zone during the first and second halves as well as during the match as a whole when compared to the time spending of the forwards.

7. RECOMMENDATIONS

This study is the first to have used heart rate and graded maximal test values to establish tertiary institution rugby game intensities as well as differences between the game intensities of forwards and backs. Furthermore, this is also the first study to show that it is a legitimate method to apply for determining the match play intensities of team sport participants. There are, however, certain shortcomings that need to be considered when interpreting the study results.

- Firstly, the results of this study must be interpreted with caution due to the specific and small population of rugby union players used in this study. Generalisation of the results to the entire rugby playing fraternity will therefore not be accurate. Further research should be conducted to determine the rugby union game demands for all levels of participation in order to put forward more relevant and specific data.
- Secondly, the small group sizes in this study may have caused outliers to have influenced the mean values of the respective heart rate intensity zones more than would have been the case with larger group sizes. For that reason, the suitability of this new method for determining the match play intensity differences between rugby union forwards and backs should be tested by means of a much larger sample of rugby players.
- Thirdly, as seen from a physiological viewpoint, the standard incremental treadmill test may not be the most suitable method for determining the heart rate intensity zones for use in analysing the rugby union match demands. The movements during the treadmill running test are continuous, forward running at constant speeds, whereas rugby games consist of running different distances, pivoting and making frequent changes in direction while constantly accelerating and decelerating. The muscle recruitment patterns and energy demands during a rugby match will therefore probably differ from those of the treadmill test. This notion was also substantiated by the difference in the average maximal heart rate values observed between the standard incremental treadmill test and the actual rugby games. However, to date, no other method or test has been designed for determining the heart rate intensity zones of athletes. As such, it can be recommended that further studies should focus on developing a more rugby-

specific incremental test for determining the two ventilatory threshold points for categorisation of the different heart rate zones.

- Lastly, it should be noted that factors such as the ranking and quality of the opponents in each of the matches, the importance of the match results, the weather conditions as well as the condition of the field of play (grassy or hard) were not considered in this study. These factors may possibly influence the percentage of time players spent in each of the heart rate intensity zones and should be considered in future studies.

Despite all of these shortcomings, this study forms a base from which other researchers can plan and conduct studies of this nature.