Heart rate and graded maximal test values to determine rugby union game intensities of adolescent boys

FRANCOIS J VZ WILLEMSE (10961542)

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SUPERVISOR: DR. BEN COETZEE

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Hierdie studie word opgedra aan my pa, wyle ds Adam J Willemse (Romeine 14 vers 8: “Of ons dan lewe of sterwe, ons behoort aan die Here.”); aan my oupa, wyle Prof FJ van Zyl, die grootste akademiese teoloog wat ek die voorreg gehad het om te kan ken; en aan my ma Annette de Jongh, sekerlik een van die grootste en veral belese intellektuele invloede in my lewe.

“No man can reveal to you aught but that which already lies half asleep in the dawning of your knowledge ... If he is indeed wise he does not bid you enter the house of his wisdom, but rather leads you to the threshold of your own mind” – Kahlil Gibran

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DECLARATION

The co-author of the two articles which form part of this dissertation, Dr Ben Coetzee (Supervisor), hereby gives the candidate, Mr Francois J vZ Willemse, permission to include the two articles as part of a Master's 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 fulfilment of the requirements for the Magister Artium 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

Despite the need to investigate the match characteristics of junior rugby union players in order to determine the physical demands that are placed on these players, only three studies have thus far focussed on the match characteristics of adolescent rugby players. It is against this problem, that the purposes of this study were firstly, to determine the heart rate and standard graded maximal oxygen uptake test values of u/15 high school rugby players; Secondly, to determine the intensities of u/15 high school rugby union games when making use of heart rates and standard graded maximal oxygen uptake test values; Thirdly, to determine if the absolute and relative total match time that is spent in each heart rate intensity zone during u/15 high school rugby games are significantly different when making use of heart rates and standard graded maximal oxygen uptake test values; Fourthly, to determine the significant positional differences in the heart rate and standard incremental maximal oxygen uptake test values of u/15 high school rugby players; Lastly, to determine the significant positional differences in the intensities of u/15 high school rugby union games when making use of heart rates and standard incremental maximal oxygen uptake test values.

The heart rates (HR) of twenty-four u/15 rugby union players (15 forwards and 9 backs) from the 1st and 2nd teams of a high school in the Potchefstroom area of the North-West Province in South Africa were monitored for the duration of several home games during the 2012 season. Furthermore, the body stature and body mass of each player were measured and each player was subjected to a standard graded maximal oxygen uptake test in the periods between rugby games. The individual heart rate intensity zones were determined by making use of this test: heart rates that corresponded to the exercise intensities below the ventilatory threshold (VT) were classified as low intensity heart rates; heart rates that corresponded to the exercise intensities between VT and the respiratory compensation point (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.

The results firstly indicated that adolescent rugby players showed an average $\dot{V}O_{2max}$ value of 49.20 ml·kg^{-1}·min^{-1}, which they obtained at an average $\dot{V}O_{2max}$ HR value of 196.94 bpm; a VT of 77.67% (154.33 bpm) of the HR_{max} that was reached at a $\dot{V}O_2$ of 31.08 ml·kg^{-1}·min^{-1}; a RCP at 87.38% of $\dot{V}O_{2max}$ (42.80 ml·kg^{-1}·min^{-1}) at an average heart rate of 184.4 bpm which was determined to be 92.72% of the HR_{max} during a standard graded maximal oxygen uptake test. Secondly, the heart rate for the three intensity zones (low (LIZ), moderate (MIZ) and high (HIZ)) were determined to be: <154.33 bpm, 154.33-184.35 bpm and >184.35 bpm, respectively. The majority of match time was spent in the MIZ (27 min and 49 s, 56.34% of the total match time), followed by the HIZ (10 min and 55 s, 23.03% of the total match time) and the LIZ (9 min and 6 s, 19.95% of the total match time). However, the average duration of low intensity bouts was higher (67 s) compared to the low (40 s) and high (39 s) intensity bouts, respectively. Lastly, significant differences were observed for all the above-mentioned values between the LIZ and MIZ as well as between the MIZ and the HIZ.

Positional comparison revealed that the backs obtained significantly higher average HR at the VT and HR's for the LIZ and MIZ as well as significantly lower average $\dot{V}O_2$ at RCP compared to the forwards. With regard to the match analysis related results, the forwards obtained significantly lower values for the total time and relative total time spent in the LIZ compared to the backs (forwards: 05 min 22 s; backs: 15 min 11 s and forwards: 12.5%; backs: 26.4%). From the results with regard to the duration of different intensity bouts, it is also clear that forwards spent less time on low intensity bouts (33 s *versus* 51 s), although the average time period that was spent on high intensity bouts was more or less the same between forwards and backs (39 s *versus* 37 s). This may be an indication of a higher work to rest ratio and less recovery time during rugby union games for the adolescent forwards compared to the backs.

To conclude, the results of this study seem to suggest that the positional specific intensities of u/15 high school rugby union games can be determined and compared by making use of these players' heart rates and standard graded maximal oxygen uptake test values. This is an important finding due to the limitations that have been identified with regard to the use of other match analysis methods. It also stresses the need for more rugby union match analysis studies on junior rugby players which make use of the last-mentioned method in order to determine the energy requirements and match demands of this group of players more accurately.

OPSOMMING

Ten spyte van die behoefte om die speleienskappe van junior rugbyuniespelers te ondersoek om die fisiese eise wat aan hierdie spelers gestel word, te bepaal, het slegs drie studies tot dusver op die speleienskappe van adolessent-rugbyspelers gefokus. Dit is met hierdie probleem in gedagte dat die doelwitte van hierdie studie eerstens was om die HT en standaard inkrementele maksimale suurstofopname-toetswaardes van o/15 hoërskool rugbyspelers te bepaal; tweedens om die intensiteit van o/15 hoërskool rugbyuniewedstryde te bepaal wanneer van HT (HT) en standaard inkrementele maksimale suurstofopname-toetswaardes gebruik gemaak is; derdens om te bepaal of die absolute en relatiewe totale wedstryd-tyd wat in elke HT intensiteitsone gedurende o/15 hoërskool rugbywedstryde deurgebring is, betekenisvol verskil wanneer daar van HT en standaard inkrementele maksimale suurstofopname-toetswaardes gebruik gemaak is; vierdens om die betekenisvolle posisieverskille in die HT en standaard inkrementele maksimale suurstofopname-toetswaardes van o/15 hoërskool rugbyspelers te bepaal; en laastens om die betekenisvolle posisionele verskille in die intensiteite van o/15 hoërskool rugbyuniewedstryde te bepaal wanneer daar van HT en standaard inkrementele maksimale suurstofopname-toetswaardes gebruik gemaak is.

Die HT van vier en twintig o/15 rugbyuniespelers (15 voorspelers en 9 agterspelers) uit die 1ste en 2de spanne van ŉ hoërskool in die Potchefstroom-omgewing van die Noord Wes Provinsie in Suid-Afrika is vir die duur van etlike tuiswedstryde gedurende die 2012-seisoen gemonitor. Voorts is die liggaamlengte en -massa van elke speler gemeet en elke speler is in die tydperke tussen rugbywedstryde aan ŉ standaard inkrementele maksimale suurstofopname-toets onderwerp. Die individuele HT-intensiteit-sones is bepaal deur van hierdie toets gebruik te maak: HT wat met die oefenintensiteite onder die ventilatoriese drempel (VD) ooreengekom het, is as lae intensiteit HT geklassifiseer; HT wat met die oefenintensiteite tussen VD en die respiratoriese kompensasiepunt (RKP) ooreengekom het, is as matige intensiteit HT geklassifiseer en HT wat met die oefenintensiteite hoër as RKP ooreengekom het, is as hoë intensiteit HT geklassifiseer.

Die resultate het eerstens aangedui dat adolessent-rugbyspelers ʼn gemiddelde $\dot{V}O_{2max}$-waarde van 49.20 ml·kg^{-1}·min^{-1}getoon het, wat hulle teen ʼn gemiddelde $\dot{V}O_{2max}$ HT-waarde van 196.94 spm verkry het; ʼn VT van 77.67% (154.33 spm) van die HT_{max} wat teen ʼn $\dot{V}O_2$ van 31.08 ml·kg^{-1}·min^{-1} bereik is; ʼn RKP teen 87.38% van $\dot{V}O_{2max}$ (42.80 ml·kg^{-1}·min^{-1}) teen ʼn gemiddelde HT van 184.4 spm wat bepaal is as 92.72% van die HT_{max} tydens ʼn standaard inkrementele maksimale suurstofopname-toets. Tweedens is die HT vir die drie intensiteitsones (lae (LIS), matige (MIS) en hoë (HIS)) bepaal as: <154.33 spm, 154.33-184.35 spm en >184.35 spm onderskeidelik. Die meeste wedstryd-tyd is in die MIS (27 min en 49 s, 56.34% van die totale wedstryd-tyd) deurgebring, gevolg deur die HIS (10 min en 55 s, 23.03% van die totale wedstryd-tyd) en die LIS (9 min en 6 s, 19.95% van die totale wedstryd-tyd). Die gemiddelde duur van lae intensiteitsbeurte was egter hoër (67 s) as die lae (40 s) en hoë intensiteitsbeurte (39 s) onderskeidelik. Laastens is betekenisvolle verskille vir al bogenoemde waardes tussen die LIS en MIS asook tussen die MIS en die HIS waargeneem.

Posisionele vergelyking het aan die lig gebring dat die agterspelers betekenisvol hoër gemiddelde HT by die VD en HT's vir die LIS en MIS asook betekenisvolle laer gemiddelde $\dot{V}O_2$ by RKP verkry het as die voorspelers. Met betrekking tot die wedstrydanalise-verwante resultate het die voorspelers betekenisvol laer waardes vir die totale tyd en relatief totale tyd wat in die LIS deurgebring is, verkry, as die agterspelers (voorspelers: 05 min 22 s; agterspelers: 15 min 11 s en voorspelers: 12.5%; agterspelers: 26.4%). Uit die resultate rakende die duur van verskillende intensiteitsbeurte is dit ook duidelik dat voorspelers minder tyd aan lae intensiteitsbeurte (33 s *versus* 51 s) bestee het, alhoewel die gemiddelde tydperk wat aan hoë intensiteitsbeurte bestee is min of meer dieselfde was tussen die voor- en agterspelers (39 s *versus* 37 s). Dit kan moontlik ʼn aanduiding van ʼn groter werk- tot rus-ratio wees en korter hersteltyd tydens rugbyuniewedstryde vir die adolessent-voorspelers as vir die agterspelers.

Ten slotte kan genoem word dat die resultate van hierdie toon dat die posisioneel spesifieke intensiteite van o/15 hoërskool rugbyuniewedstryde bepaal en vergelyk kan word deur van daardie spelers se HT en standaard inkrementele maksimale suurstofopname-toetswaardes gebruik te maak. Dit is ŉ belangrike bevinding weens die beperkings wat met betrekking tot die gebruik van ander wedstrydanalise-metodes geïdentifiseer is. Dit beklemtoon ook die behoefte aan meer rugbyuniewedstryd analise-studies op junior rugbyspelers, wat van laasgenoemde metode gebruik maak om die energievereistes en wedstrydeise van hierdie groep spelers meer akkuraat te bepaal.

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LIST OF ABBREVIATIONS

bpm	beats per minute
h	hour
HIA	high intensity activities
HRavg	average heart rate
HRmax	maximum heart rate
HRmin	minimum heart rate
IRB	International Rugby Board
$km \cdot h^{-1}$	kilometre per hour
LIA	low intensity activities
LIZ	low intensity zone
m	meter
min	minute
MIZ	moderate intensity zone
$ml \cdot kg^{-1} \cdot min^{-1}$	millilitre per kilogram per minute
mm/L	millimol per litre
n	number of subjects
RCP	respiratory compensation point
RER	respiratory exchange rate
RERmax	maximum respiratory exchange rate
s /sec	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	ventilatory threshold

CHAPTER 1:

1 INTRODUCTION

1. PROBLEM STATEMENT

Rugby is a highly demanding sport that places a considerable amount of physical stress on the anaerobic energy sources, while the aerobic energy system is used in sub-maximal activities and aids in repeated efforts and recovery (Duthie *et al.*, 2003:974; Meir *et al.*, 2001:453). A variety of physiological responses are, however, elicited by the activities in rugby due to the repeated high-intensity sprints and frequent contact situations players face during a game (Duthie *et al*., 2003:974). The wide range of physiological responses and demands as well as the position-specific requirements make rugby exceptionally complex to analyse compared to individual sports (Kaplan *et al.*, 2008:92; Deutsch *et al.*, 2007:462; Duthie *et al*., 2003:974; Quarrie *et al.*, 1996:53). Coaches, sport scientists and other sport-related professionals need to have an understanding of the specific demands of rugby in order to plan and implement the most effective training programs and testing procedures for rugby players (Coutts *et al.*, 2003:98; Deutsch *et al.*, 2002:160; Meir *et al.,* 2001:451). Deutsch *et al.* (2008:803) supported this notion by concluding that specificity in testing and training is unlikely to be achieved without information regarding the demands of and differences between playing positions.

The training and development of elite rugby players should, however, start at junior level in order to establish core physical and physiological qualities that can be fine-tuned at a later stage (Duthie, 2006:2). However, the majority of development programs for juniors are based on the content, practices and physiological make-up of elite senior players (Duthie, 2006:3). This statement is supported by Hartwig *et al.* (2008:94) who also concluded that the training and game demands of sports are becoming increasingly more intense and comparable to those of adult sports instead of being suitable for adolescent sports. Hartwig *et al*. (2008:94) further contend that the volume of participation in sport by younger rugby players (training and competition) needs to be monitored to determine the most appropriate workloads that will ensure future participation and performance is not compromised. In spite of previous recommendations, the physical demands of high school rugby union on players are poorly documented, and no evidence-based strategies exist to monitor participation loads (Hartwig *et al*., 2008:95).

In general, researchers and practitioners apply time-motion analysis (Sykes *et al*., 2009; Barbero-Alvarez *et al*., 2008; Davidson & Trewartha 2008), heart rate recordings and analyses (Atkins, 2006; Coutts *et al*., 2003; Capranica *et al*., 2001) as well as blood lactate monitoring (Atkins, 2006; Coutts *et al*., 2003; Capranica *et al*., 2001) to determine the amount of work and the work intensities of team sports. The time-motion analysis method differentiates between observable movement patterns players perform during a match such as standing still, walking, jogging and sprinting (Deutsch *et al*., 2007:464; Van der Merwe, 1989:32-33; Docherty *et al*, 1988:271). Only two studies in which time-motion analyses were performed on junior rugby union games (under 19 and younger) could be traced. One study on u/16 rugby players applied time-motion analyses to compare the characteristics of training with those of match play (Hartwig *et al.*, 2006:16). These researchers found no significant difference between the frequency of stationary (37% *versus* 43%), walking (45% *versus* 35%) and jogging movements (14% for both training and match) when the characteristics of training and match play were compared (Hartwig *et al.*, 2006:16). In contrast, striding (4% *versus* 6%), sprinting (0.5% *versus* 2%), maximal sprinting (0.02% versus 1%), total distance covered (4.4 km *versus* 5.8 km), average running speed (3.3 km/h *versus* 4.3 km/h) and the total time sprinting (33 s *versus* 108 s) were significantly higher during match play than that observed during training. Another time-motion analysis study by Hartwig *et al.* (2008:95) did, however, only focus on the training volume and intensities of 14 to 18-year-old players during a season and not during match play.

A shortcoming of the time-motion analysis method is that no physiological measurements are taken. According to Nicholas (1997:379), time-motion analysis that determines the distances travelled, the time engaged in different activities and the frequency of movement occurrences for the estimation of the physiological demands of rugby may underestimate the total demands of match-play due to the indirect work-method used. In this regard, Reilly (as quoted by Nicholas, 1997:379) also observed that players required additional energy to accelerate, decelerate, run forward or laterally, for jumping, pushing, tackling and other game activities. The observer's knowledge, the perceived seriousness of the competition, the focus of attention, the state of arousal and the anticipation of certain events are factors that can influence the objectivity of the observations, which may lead to measurement errors (McKenzie *et al*., 1989:102). The validity of time-motion analysis with regard to intensity can be questioned due to the simplification of movement patterns into categories when actual play involves dynamic combinations of tasks, skills and tactics (Duthie *et al.* 2003:983). This point was further substantiated in the study of Duthie *et al.* (2003:270) who concluded that the time-motion analysis' results of rugby union are only moderately reliable when conducted by an experienced observer. In view of these shortcomings with regard to the use of time-motion analysis alone for determining the physiological demands of rugby union, Deutsch *et al.* (1998:562) recommended the combined use of accurate and reliable time-motion analysis with heart rate analysis.

A direct linear relationship exists between heart rate and oxygen uptake, which is an indirect estimation of energy expenditure (Coutts *et al.,* 2003:98; Deutsch *et al.*, 1998:561) or overall physiological stress (Coutts *et al.*, 2003:100) for various intensities of exercises (Deutsch *et al.*, 1998:562). Buttifant (1999:809) showed that the monitored heart rate responses of players confirmed the strenuous demands of Australian Rules Football and in a study on futsal (indoor, five-a-side soccer), Barbero-Alvarez *et al.* (2008:65) used heart rates (associated with different maximal oxygen uptakes or $\dot{V}O_{2max}$ values), to prescribe exercise intensities. Researchers have therefore proposed the measurement and use of heart rate and oxygen consumption to quantify exercise intensities (Gamble 2007:63). It is therefore possible to use heart rate to estimate the average work intensities of players during rugby games (Duthie *et al.*, 2003:986; Deutsch *et al.*, 1998:561)**.**

The use of heart rate guidelines only may, however, lead to errors in the estimation of exercise intensities and energy system contributions due to individual differences in fitness levels and variations in exercise economy (Achten & Jeukendrup, 2003:526). In view of these limitations in using heart rate values only 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 $\dot{V}O_2$ during a graded maximal test allows researchers to identify two physiological gas exchange points, namely the aerobic threshold/ventilatory threshold point (VTP) and the anaerobic threshold/respiratory compensation point (RCP) (Chicharro *et al.*, 2000:450). The heart rates that correspond to the exercise intensities below the VTP, between the VTP and RCP, and above the RCP are then determined to classify the different exercise-intensity heart rates (Chicharro *et al.*, 2000:450). In spite of the benefits that can be derived from the use of this technique, only one study has made an attempt to use this technique for determining the game intensities of university-level rugby union players (Sparks, 2010:32). Yet researchers have used this technique with success among individual sport participants such as road cyclists (Chicharro *et al.*, 2000:452).

Despite the fact that all of the above-mentioned research findings seem to suggest that the demands of high school rugby union games need to be quantified for sport scientists to construct appropriate conditioning programs for this group of players, no researchers have made an attempt to quantify the intensities of rugby union games of a South African high school rugby union team. It is in the light of this research background and identified shortcomings that the following research questions are posed: Firstly, what are the heart rate and standard graded maximal oxygen uptake test values of u/15 high school rugby players? Secondly, what are the intensities of u/15 high school rugby union games when making use of heart rates and standard graded maximal oxygen uptake test values? Thirdly, are there significant differences in the absolute and relative total match time that is spent in each heart rate intensity zone during u/15 high school rugby games when making use of heart rates and standard graded maximal oxygen uptake test values? Fourthly, what are the significant positional differences in the heart rate and standard incremental maximal oxygen uptake test values of u/15 high school rugby players? Lastly, what are the significant positional differences in the intensities of u/15 high school rugby union games when making use of heart rates and standard incremental maximal oxygen uptake test values?

Results of this study could possibly enable future coaches, rugby players and sport scientists of u/15 high school rugby teams to compile conditioning programs specifically in accordance with the demands of rugby games. It may also assist those in the last-mentioned capacities to adjust the u/15 high school players' conditioning programs in accordance with the different demands placed on front and backline players.

2. OBJECTIVES

The objectives of this study are to:

- Determine the heart rate and standard graded maximal oxygen uptake test values of u/15 high school rugby players;
- Determine the intensities of u/15 high school rugby union games when making use of heart rates and standard graded maximal oxygen uptake test values;
- Determine if the absolute and relative total match time that is spent in each heart rate intensity zone during u/15 high school rugby games are significantly different when making use of heart rates and standard graded maximal oxygen uptake test values.
- Determine the significant positional differences in the heart rate and standard incremental maximal oxygen uptake test values of u/15 high school rugby players;
- Determine the significant positional differences in the intensities of u/15 high school rugby union games when making use of heart rates and standard incremental maximal oxygen uptake test values.

3. HYPOTHESES

The study is based on the following hypotheses:

- Hypotheses 1 and 2: Due to the fact that no research exists that has made an attempt to use the mentioned technique to classify the different exercise intensity heart rates and to determine the game intensities of high school rugby union games positionally, no hypotheses were set for the first and fourth purposes of the study.

- Hypothesis 3: Under 15 high school rugby union games will be characterised by more low and moderate-intensity activities compared to high-intensity activities when making use of heart rates and standard graded maximal oxygen uptake test values.
- Hypothesis 4: Significant differences will exist with regard to the absolute and relative total match time that was spent in each heart rate intensity zone during u/15 high school rugby games when making use of heart rates and standard graded maximal oxygen uptake test values.
- Hypothesis 5: Under 15 forwards will obtain significant higher values for the amount and percentage of time spent in the high intensity heart rate zone compared to the backs, whereas the u/15 backs will obtain significant higher values for the amount and percentage of time spent in the low intensity heart rate zone compared to the forwards during high school rugby union games when making use of heart rates and standard incremental maximal oxygen uptake test values.

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: Introduction. 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 different methods for analysing 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 – Determining adolescent boys' rugby union game intensities using heart rates and graded maximal test values. The article will be presented to 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 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 – Heart rate and graded maximal test values to determine positional Rugby Union game intensities of adolescent boys. The article will be presented to 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 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, limitations and recommendations.

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CHAPTER: 2

2 LITERATURE REVIEW: THE DIFFERENT METHODS FOR ANALYSING THE GAME INTENSITIES OF RUGBY UNION

1. Introduction

In any type of sport, objective performance feedback is very important for both the athlete and the coach so that optimal training and further performance improvements can take place (Franks, 2009:9). In this regard an understanding of the specific demands of rugby union will enable coaches, sport scientists and other sport-related professionals to plan and implement the most effective training programs and testing procedures for rugby players (Meir *et al.,* 2001:451; Deutsch *et al.*, 2002:160; Coutts *et al.*, 2003:98). Performance analysis could provide coaches with valuable support in this regard (Agnew, 2006:2). Some of the methods applied in recent years for determining the duration, types and frequency of different activities and movement patterns as well as the amount of work and work intensities of rugby games are notational analysis (Van der Merwe, 1989; Lyons (cited by Hughes & Franks), 2009; Hughes & Bartlett, 2009:), time-motion analyses (Duthie *et al*. 2005; Hartwig *et al.*, 2006; Deutsch *et al.* 2007; Roberts *et al.*, 2008), GPS analyses (Duthie *et al.*, 2005; Hartwig *et al.*, 2006; Deutsch *et al.*, 2007), blood lactate monitoring and analyses (Deutsch *et al.*, 1998), heart rate recording and analyses (Deutsch *et al.*, 1998) as well as the combined use of heart rates and graded maximal test values (Sparks, 2010).

In view of the last-mentioned facts, the aims of this literature review were to firstly present the results of research that have investigated the use of each of the above-mentioned methods for determining the demands of senior and junior rugby union matches. The second aim was to highlight the shortcomings with regard to the use of each of the methods. Thirdly, the aim was to explain the rule differences between senior and junior rugby and lastly, to compare the match analyses' results of each of the methods between senior and junior rugby matches. The following inclusion criteria were applied in the identification of the relevant literature for this review: The literature searches were narrowed down to include only articles from the past 24 years (1988–2012) which made use of rugby union or rugby league players that were 15 years of age or older and that either played on club, provincial (national), Super 12/14 or international level. Only studies that focussed on the match or training analyses profile of rugby union or rugby league players were included. All studies that did not meet the inclusion criteria were excluded and not used in the literature review.

2. The analysis of senior rugby union games

2.1 Introduction

Rugby is a highly demanding sport that places a considerable amount of stress on the anaerobic energy sources, while the aerobic energy system is used in sub-maximal activities and aids in repeated efforts and recovery (Meir *et al.*, 2001:453; Duthie *et al.*, 2003:974). A variety of physiological responses are, however, elicited by rugby due to the repeated high-intensity sprints and frequent contact situations players face during a game (Duthie *et al.*, 2003:974). The wide range of physiological responses and demands as well as the position-specific requirements make rugby exceptionally complex to analyse compared to individual sports (Duthie *et al.*, 2003:974; Deutsch *et al.*, 2007:462). In view of this researchers have made use of a wide range of match and training analysing methods in order to determine the profiles of the last-mentioned activities. Some of the oldest methods for analysing rugby match play are notational and time motion analyses.

2.2 The use of notational analysis for analysing rugby union games

Notational analysis is a method of time-motion analysis, by means of which play is analysed by annotating matches for the description of tactics and technique (Wikipedia, 2011). Hughes and Bartlett (2008:9) indicated that it is an objective method for recording the performances of teams or individuals for quantitative and qualitative feedback. Notational analysis has traditionally focused on team and match play sports and mostly studied open skills such as interactions between players, movement patterns and individual or team behaviour (Hughes & Bartlett, 2009:169). Hughes and Franks (2009:106) stated that notational analysis methods would be sufficient and reliable for coaches, sport scientists as well as other sport-related professionals to increase their insights into the performances of different sports as long as accurate results are produced. Notational analysis does, however, make use of very expensive and sophisticated systems, compared to the simple pen and paper analysis method (Hughes & Franks, 2009:106).

Several researchers have used notational analysis to describe different indicators and aspects of several sports. For example, as early as 1987 and 1989 Van der Merwe (1989:32-33) made use of notational analyses to quantify different set-piece moves (i.e. number of scrums, line-outs, passes, kicks and penalties) during rugby union match play. Hughes and Bartlett (2009:180) used another approach and divided the match descriptors for invasion games (such as goal-throwing, try-scoring and goal-striking games) into the following match indicators: technical, tactical and biomechanical indicators. In this regard, technical indicators were described as those focussing on the technical actions of players/teams during the match such as successful and unsuccessful line-outs, passes etc. Under this category the total number of actions performed successfully and unsuccessfully were also indicated in order to portray the margin of error, for example 7 successful passes out of a total of 10 passes is equal to a 30% margin of error (Hughes & Bartlett, 2009:181). Tactical indicators focussed on aspects such as teamwork, pace, fitness and movement (Hughes & Bartlett, 2009:181). Although fitness was noted as one of the match descriptors by the last-mentioned authors, no measurement or indication of energy expenditure was provided. Biomechanical indicators evaluated the execution of actions or skills, for instance the execution of the place kick in order to identify all the biomechanical aspects involved (Hughes & Bartlett, 2009:182).

2.2.1 Shortcomings with regard to the use of notational analysis for determining the demands of rugby union games

Studies have shown that the use of visual observations by an individual (such as a coach) in order to gather information with regard to the demands of a certain sport (real-time notational analyses), can lead to errors and is therefore not an objective way of gathering data and make accurate conclusions with regard to the demands of different sports codes (Franks, 2009:13). Franks (2009:13) found accuracies of less than 45% correctness when match or post-game assessments were evaluated. When the situation is such that real-time notational analysis is not possible, post-event analysis by means of slow motion and the replay functions on DVD players could offer a resolve to the last-mentioned problem (Franks, 2009:16).

2.3 The use of time-motion analysis (TMA) for analysing rugby union games

The term TMA refers to the process of determining the time periods of each task executed during training or matches (Van der Merwe, 1989:17). Time-motion analysis can also be utilized for analysing the nature, duration and frequency of movements or activities performed during the execution of these specific tasks (Van der Merwe, 1989:17; O'Donoghue, 2008:191).

In order to conduct a TMA on a rugby union game, players are generally divided into four player groupings for measurement of movements: front row forwards (props and locks), back row forwards (hookers, flankers and the eighth men), inside backs (scrum halves, fly halves and centres) and outside backs (wings and full backs) (Deutsch *et al.* 1998:562; Duthie *et al*. 2005:523; Deutsch *et al.* 2007:462; Roberts *et al.* 2008:825). The different movement patterns are categorised and documented by differentiating between the observable velocities of movements such as standing still, walking, jogging, running, sprinting and static high-intensity exertions (Docherty *et al.*, 1988:271; Van der Merwe 1989:32; Deutsch *et al.* 1998:562; Duthie *et al*. 2005:523; Hartwig *et al.*, 2006:16; Deutsch *et al.* 2007:463; Roberts *et al.* 2008:825). Roberts *et al*. (2008:829) and O'Donoghue (2008:191) categorised activities such as standing, walking and jogging into low-intensity activities and activities such as running, sprinting, shuffling as well as on the ball activities or challenging for the ball activities into high-intensity activities. The results of rugby games are expressed as the total distance covered during a match, the average duration of each movement, the maximum duration of movements, the total duration of movements and the percentage of match time spent on each movement pattern (Docherty *et al.*, 1988:271; Deutsch *et al.*, 1998:562; Duthie *et al*., 2005:523; Deutsch *et al.*, 2007:463; O'Donoghue, 2008:191; Roberts *et al.*, 2008:828). Another important result of TMA is the work to rest/recovery ratio (Deutsch *et al.*, 1998:567; Duthie *et al.*, 2003:984; Duthie *et al*., 2005:526; Deutsch *et al*., 2007:467; O'Donoghue, 2008:196). The work to rest ratio values provide the researcher, sport scientist or coach with information on the objective and quantifiable physiological requirements of an activity (Duthie *et al.*, 2003:984).

2.3.1 Results of TMA on rugby union match play

The results of the following match analysis-related aspects will be discussed: a) Total distances covered during a match; b) Movement patterns executed during a match and c) The work:rest ratios of rugby games.

a) Total distances covered during a match

The summarized research results with regard to the total distances covered during matches for different positional groups are presented in Table 1.

Table 1: The summarized research results with regard to the average total distances covered during different rugby matches

References	Population	Forwards	Backs	Average
Total distances during match play (m)				
Deutsch *et al.* (1998:565)	u/19 Elite	4240	5640	4800
Roberts *et al.* (2008:828)	English premier	5580	6124	5859.7
Austin (2011:259)	Super 14 (2008/2009)	5280.5	5939	5609.8

From Table 1 it is notable that the average total distance covered during a rugby match varies between 4 800 m and 5 859.7 m with the backs that normally cover the largest average total distances during a rugby match.

b) Movement patterns executed during a match

The literature-reported results with regard to the different movement patterns observed in matches by means of TMA will be discussed next. Before a discussion of each movement pattern can take place, it is important to firstly present the summarized literature results of each category of movement patterns in table format. The first category of movement patterns that can be identified from TMA is standing still or situations during which players are inactive during a game. The summarized results of the occurrence of standing still or situations during which players were inactive during games are presented in Table 2.

Table 2: The summarized research results with regard to standing still or situations during which players are inactive during different rugby matches

References	Population	Forwards	Backs	Average
Average duration of movement/activity (sec)				
Duthie *et al.* (2005:527)	2001 Super 12	11.3	11.9	11.6
Total duration of movement (min)				
Duthie *et al.* (2005:526)	2001 Super 12	36.4	33.01	34.7
Percentage of total match time spent on the above-mentioned movements (%)				
Duthie *et al.* (2005:526)	2001 Super 12	41.0	41.0	41.0
Roberts *et al.* (2008:829)	English premier	32.4	29.1	30.8

From Table 2 it is clear that a vast amount of time was spent on standing still or that situations occurred during which players were inactive during a game (34.7 min on average) with as much as 41% of the total match time spent on this category of movement patterns. The percentage of match time spent standing still seemed to have declined from an average of 41% in 2001 (Duthie *et al.*, 2005:526) to 30.8% in 2002-2004 (Roberts *et al.*, 2008:829). The latter results, however, were from analysis of elite club rugby players situated in the northern hemisphere; thus a comparison between the two styles of rugby may be problematic.

These periods of inactivity can be regarded as those of recovery, although the average duration of these inactive periods during a game is too brief to allow for the total replenishment of the Adenosine Triphosphate-Creatine Phosphate (ATP-CP) stores. According to Deutsch *et al*. (2007:470), recovery periods of less than 20 sec would not be sufficient for the total replenishment of the ATP-CP stores after active periods of 10 sec or more. However, the tabulated results suggest that from time to time players get maximum recovery periods of 58.8 to 68.4 sec. This insufficient replenishment of the alactic energy system would result in the engagement of the anaerobic lactic system for energy production (Deutsch *et al.,* 1998:569; Jansen, 2001:2) due to the fact that players need 3 to 5 minutes rest for the total resynthesis of ATP-CP stores (Jansen, 2001:2). Table 3 presents the summarized results of studies that analysed the time periods and percentage of total match time players spent on walking.

Table 3: The summarized research results with regard to walking during different rugby matches

References	Population	Forwards	Backs	Average
Average duration of movement/activity (sec)				
Deutsch *et al.* (1998:566)	u/19 Elite	8.7	10.0	9.3
Duthie *et al.* (2005:527)	Super 12	7.5	10.4	9.0
Maximum duration of movement (sec)				
Deutsch *et al.* (1998:566)	u/19 Elite	41.4	46.6	44.0
Total duration of movement (min)				
Duthie *et al.* (2005:526)	Super 12	23.7	33.3	28.5
Percentage of total match time spent on the above-mentioned movement (%)				
Duthie *et al.* (2005:526)	Super 12	27.0	38.0	32.5
Deutsch *et al.* (2007:465)	Super 12	23.4	43.6	33.5
Roberts *et al.* (2008:829)	English premier	35.1	46.0	40.6

Again, the tabulated results seem to suggest that players spend a high percentage of the total match time on walking activities. Interestingly, the results show that the average percentage of total match time spent on walking for both player groups in the Super 12 Tournament has risen from 32.5% in 2005 to 33.5% in 2007. One study in particular reported an average value for the last-mentioned variable as high as 40.6% for English Premiership players in 2008 (Roberts *et al.*, 2008:829). The larger the amount of time spent (38% - 46%) on walking during a match would probably allow the backline players more time to recover between high-intensity activities compared to the forwards that spend less time on walking during a match (23.4% - 35.1%). Despite the result that a high percentage of match time was spent on walking activities, the brief average duration of walking activities (9.0-9.3 sec) during a match would suggest that these types of activities are only used for brief moments in between higher intensity activities. Table 4 presents the summarized results of the time periods and percentage of total match time players spent on jogging.

Table 4: The summarized research results with regard to jogging during different rugby matches

References	Population	Forwards	Backs	Average
Average duration of movement/activity (sec)				
Deutsch *et al.* (1998:566)	u/19 elite	6.00	5.4	5.7
Duthie *et al.* (2005:527)	Super 12	5.8	4.8	5.3
Deutsch *et al.* (2007: 465)	Super 12	6.6	5.7	6.2
Maximum duration of movement (sec)				
Deutsch *et al.* (1998:566)	u/19 elite	18.6	18.4	18.5
Total duration of movement (min)				
Duthie *et al.* (2005:526)	Super 12	17.6	14.0	15.8
Percentage of total match time spent on the above-mentioned movement (%)				
Duthie *et al.* (2005:526)	Super 12	20.0	16.0	18.0
Deutsch *et al.* (2007:465)	Super 12	23.9	22.3	23.0
Roberts *et al.* (2008:829)	English premier	17.0	17.0	17.0

The tabulated results show that only brief periods of time are spent on jogging during a match (5.3-6.2 sec), while the average percentage of total match time spent on this movement pattern ranges between 18% and 23.0%. A further analysis of data would also suggest that the average total match time rugby players of the same participation level spend on jogging has decreased from 23.0% in 1996 to 18% in 2005.

Table 5 presents the summarized results of the time periods and percentage of total match time players spend on striding. Striding can be defined as the running activities that occur at velocities above jogging and below those of sprinting.

Table 5: The summarized research results with regard to striding during different rugby matches

References	Population	Forwards	Backs	Average
Average duration of activities (sec)				
Deutsch *et al.* (1998:566)	u/19 Elite	2.6	2.45	2.5
Duthie *et al.* (2005:527)	Super 12	2.5	2	2.3
Deutsch *et al.* (2007:465)	Super 12	3.5	4	3.8
Maximum duration of movement (sec)				
Deutsch *et al.* (1998:566)	u/19 Elite	5.5	5.5	5.5
Total duration of movements (min)				
Duthie *et al.* (2005:526)	Super 12	1.52	1.9	1.7
Percentage of total match time spent on the above-mentioned movement (%)				
Duthie *et al.* (2005:526)	Super 12	1.7	2.1	1.9
Deutsch *et al.* (2007:465)	Super 12	1.2	2.5	1.4
Roberts *et al.* (2008:829)	English premier	4.1	4.1	4.1

Table 5 indicates that an increase from 1.9% to 4.1% occurred with regard to the average percentage of total match time spent on striding from 1998 to 2007. All the results suggest that players spend a small amount of time on striding during a match.

Table 6 presents the results with regard to the sprinting patterns of players during rugby matches. Docherty *et al.* (1988:271) defined sprinting as “running at maximum speed or full effort”. A clear pattern emerged when the different measurements of sprinting were compared between older and more recent matches. The results show that players spend a higher average percentage of total match time on sprinting (1.9%) than revealed by previous analyses (0.4-1.0%). The rule changes of January 2000 are thought to be the biggest contributor to these increases (Williams *et al.*, 2005:9). These rule changes included changes to improve recycling at the breakdowns, the turnover scrum rule and rules for improving lifting during line-outs (Williams *et al.,* 2005:8).

Table 6: The summarized research results with regard to sprinting during different rugby matches

References	Population	Forwards	Backs	Average
Average duration of movement (sec)				
Deutsch *et al.* (1998:566)	u/19 Elite	2.6	2.45	2.5
Duthie *et al.* (2005:527)	Super 12	2.5	2	2.3
Deutsch *et al.* (2007:465)	Super 12	2	3.2	2.6
Maximum duration of movement (sec):				
Deutsch *et al.* (1998:566)	u/19 Elite	3.2	4.0	3.6
Duthie *et al.* (2005:527)	Super 12	6.4	7.5	7.0
Deutsch *et al.* (2007:465)	Super 12	3.3	6.2	4.8
Total duration of movements (min):				
Duthie *et al.* (2005:526)	Super 12	0.45	1.3	0.9
Percentage of total match time spent on the above-mentioned movement (%)				
Duthie *et al.* (2005:526)	Super 12	0.5	1.5	1.0
Deutsch *et al.* (2007:465)	Super 12	0.2	0.6	0.4
Roberts *et al.* (2008:829)	English premier	1.5	2.2	1.9

Table 7 presents the summarised results of time periods and percentage of total match time players spend on static exertion types of activities. Static exertion types of activities include scrumming, rucking, mauling, tackling and activities where players compete for the ball (Docherty *et al.,* 1988:271; Duthie *et al.,* 2005:525; Roberts *et al.,* 2008:825). The results suggest that static exertion types of activities did not increase from 1998 to 2008, although not enough scientific evidence, especially with regard to the percentage of total match time spent on these types of activities are available to support a definite conclusion.

Table 7: The summarized research results with regard to static exertion types of activities during different rugby matches

References	Population	Forwards	Backs	Average
Average duration of activities (sec)				
Deutsch *et al.* (1998:566)	u/19 elite	5.45	4.99	5.2
Duthie *et al.* (2005:527)	Super 12	7.1	3.8	5.5
Roberts *et al.* (2008:829)	English premier	5.2	3.6	4.4
Maximum duration of movement (sec)				
Deutsch *et al.* (1998:566)	u/19 elite	13.25	8.3	10.8
Total duration of movements (min)				
Duthie *et al.* (2005:526)	Super 12	9.1	1.32	5.2
Percentage of total time spent on above-mentioned movement (%)				
Duthie *et al.* (2005:526)	Super 12	10	1.5	5.8
Roberts *et al.* (2008:829)	English premier	9.9	1.6	5.8

The summarised studies results with regard to the percentage of total match time spent on different intensities of activities are presented in Table 8 and 9. For the analyses of these results standing still, walking and jogging were categorised as low-intensity activities whereas striding, sprinting and static exertion types of activities were categorised as high-intensity activities according to the guidelines of Duthie *et al*. (2003:984). The results in Table 8 show that the majority of game time (60.7% to 91.5%) was spent on low intensity activities (LIA). With regard to the percentages of time spent on LIA during Super 12 matches, Duthie *et al*. (2005:527) and Deutsch *et al*. (2007:465) found that the majority of the LIA comprised standing still with 41% and

44.4% of the total match time spent on this activity. Analyses of English Premier Rugby Union matches revealed different results for LIA with 40.6% of the match time spent on walking compared to 30.8% spent on standing still (Roberts *et al*., 2008:829). The fact that the two categories of matches analysed differed with regard to the level of competitions and the hemisphere of participating teams (Super 12 rugby in the southern hemisphere versus English Premiership rugby in the northern hemisphere) may provide a possible explanation for the differences in LIA results. In this regard Williams *et al*. (2005:10) found that the ball was in play for longer periods of time during the 2003 matches played in the northern hemisphere compared to those played in the southern hemisphere. Roberts *et al*. (2008:831) further suggested that contrasting styles of play between the northern and southern hemisphere teams were the reason for the differences in time motion analysis results. More recent research by Austin (2011:261) reported the total percentages of match time spent in LIA during the Super 14 Tournament to be 64.5% for the forwards and 57% for the backs. These results would suggest that the time spent in LIA in Super rugby has decreased over the period from 1996 to 2009.

The majority of results in Table 9 show that a minority of time was spent on HIA (5.3% to 33.5%). The available research shows that static exertion types of activities have the highest occurrence during rugby matches, with between 2.9% and 5.8% of the total match time spent on these activities (Duthie *et al.*, 2005:527; Deutsch *et al.,* 2007:465; Roberts *et al.*, 2008:829). Striding seems to be the high-intensity activity that obtained the second highest percentages, namely between 1.9% and 4.1% of match time spent on it, whereas sprinting was identified as the high-intensity activity with the lowest percentage of match time spent on it (0.4% - 1.9%). From the summarised results it is also clear that the percentages of total match time spent on HIA have increased considerably over time with more recent analysis of Super 14 rugby matches (2008/2009) that revealed a much higher average percentage for the amount of time spent on HIA (33.5%) during matches (Austin *et al.*, 2011:261) compared to analyses (5.3-8.7%) of previous matches in the Super Tournament series (1996/1997 and 2001/2002) (Duthie *et al.*, 2005:527; Deutsch *et al.,* 2007:465). This increase in HIA and corresponding decrease in LIA strongly suggest that match intensities have risen from 1996 to 2009.

Table 8: Total percentages of match time spent on low-intensity activities (LIA) during different rugby matches

References	Forwards	Backs	Average
Percentage of total match time spent standing still (%)			
Deutsch *et al.* (2007:465) 1996/1997 Super 12	47.7	41.1	44.4
Duthie *et al.* (2005:526) 2001/2002 Super 12	41	41	41
Roberts *et al.* (2008:829) English premier	32.4	29.4	30.8
Percentage of total match time spent walking (%)			
Deutsch *et al.* (2007:465) 1996/1997 Super 12	17.9	32.4	25.2
Duthie *et al.* (2005:526) 2001/2002 Super 12	27	38	32.5
Roberts *et al.* (2008:829) English premier	35.1	46	40.6
Percentage of total match time spent jogging (%)			
Deutsch *et al.* (2007:465) 1996/1997 Super 12	21.0	17.3	19.2
Duthie *et al.* (2005:526) 2001/2002 Super 12	20	16	18
Roberts *et al.* (2008:829) English premier	17	17	17
Total LIA (%)			
Deutsch *et al.* (2007:465) 1996/1997 Super 12	86.6	90.8	88.7
Duthie *et al.* (2005:526) 2001/2002 Super 12	88	95	91.5
Duthie *et al.* (2003:984) Club to International	-	-	85
Roberts *et al.* (2008:829) English premier	84.5	92.4	88.4
Austin *et al.* (2011:261) Super 14	64	57	60.7

Position-specific results seem to suggest that forwards spend between 64% and 88% on LIA during a rugby match, compared to the backs that spend considerably more time on these types of activities (between 57% and 95%) (Duthie *et al*., 2005:527; Deutsch *et al*., 2007:465; Roberts *et al*., 2008:829; Austin *et al*., 2011:261). However, the average percentages of match time spent on LIA for both player groups decreased from 88.7% for the 1996/1997 Super 12 rugby seasons (Deutsch *et al*.,2007:465) to 60.7% for the 2009 Super 14 rugby season (Austin *et al*., 2011:261). At the same time, the HIA averages of both player groups increased from 5.3% (Deutsch *et al*., 2007:465) to 33.5% (Austin *et al*., 2011:261). These changes in percentage of time spent on LIA and HIA during matches in each of the positional groups are an indication that the intensity of rugby matches are increasing over time and that the recovery periods are decreasing. These results would also suggest that less playing time is spent on activities that make use of energy from the aerobic energy system (LIA) and more time on activities that make use of energy from the anaerobic energy system (HIA). Furthermore, the tabulated results show that the forwards spend more time on static exertion types of activities during matches compared to all other HIA, which may place a higher demand on these players to exert strength and power during match play. In contrast, the HIA on which the backs spend the most time during a rugby match was striding. In view of this result, it can probably be assumed that a higher demand will be placed on the speed and speed endurance capacity of backs compared to forwards during match play.

Table 9: Total percentages of match time spent on high-intensity activities (HIA) during different rugby matches

References	Forwards	Backs	Average
Percentage of total match time spent striding (%)			
Deutsch *et al.* (2007:465) 1996/1997 Super 12	1.2	3.8	2.5
Duthie *et al.* (2005:526) 2001/2002 Super 12	1.7	2.1	1.9
Roberts *et al.* (2008:829) English premier	4.1	4.1	4.1
Percentage of total match time spent sprinting (%)			
Deutsch *et al.* (2007:465) 1996/1997 Super 12	0.2	0.6	0.4
Duthie *et al.* (2005:526) 2001/2002 Super 12	0.5	1.5	1.0
Roberts *et al.* (2008:829) English premier	1.5	2.2	1.9
Percentage of total match time spent on static exertion types of activities (%)			
Deutsch *et al.* (2007:465) 1996/1997 Super 12	4.8	0.9	2.9
Duthie *et al.* (2005:526) 2001/2002 Super 12	10	1.5	5.8
Roberts *et al.* (2008:829) English premier	9.9	1.6	5.8
Percentage of total match time spent in HIA (%)			
Deutsch *et al.* (2007:465) 1996/1997 Super 12	5.3	5.2	5.3
Duthie *et al.* (2005:526) 2001/2002 Super 12	13.9	5.1	8.7
Duthie *et al.* (2003:984) Club to International			15
Roberts *et al.* (2008:829) English premier	15.5	7.9	11.8
Austin *et al.* (2011:261) Super 14	31.5	35.5	33.5

c) The work:rest ratios of rugby games

The different work:rest ratios reported for rugby union games are presented in Table 10. The results in Table 10 show that the average work:rest ratios of different rugby matches ranged between 1:5 and 1:14.4. As expected, the forwards in each of the tabulated studies showed lower average work:rest ratios (between 1:4 and 1:8.3) than the backs (between 1:5.5 and 1:21.8).

Table 10: The average work:rest ratios for the activities performed during different rugby union matches

References	Forwards	Backs	Average
Work:rest ratio			
Deutsch *et al.*(2007:467) Super 12 1996/97	1:7.4	1:21.8	1:14.4
Duthie *et al.* (2005:523) Super 12 2001/02	1:8	1:18	1:13
Eaton and George (2005:26) 2005	1:8.3	1:13	1:12
Austin *et al.* (2010:259) Super 14 2008/2009	1:4	1:5.5	1:5

These results show that the forwards spend more match time in HIA and less time in LIA than the backs. The differences in work:rest ratios between the two positional groups are also an indication that forwards spend less time resting than the backs. Furthermore, the results in Table 5-7 suggest that forwards spend 3.72 sec on average during a rugby match on HIA such as striding, sprinting and static exertion types of activities, which would mean that the anaerobic alactic energy system will possibly play an important role in contributing to the energy requirements of these activities. However, due to the short periods of rest (4 to 8.3 times the work period = 14.9 to 30.9 sec) that follow the HIA work periods, the body will not have enough time for the total replenishment of the phosphate stores and will therefore be forced to rely more on the anaerobic glycolysis energy pathway for energy delivery (Deutsch *et al.,* 1998:569; Jansen, 2001:2). This is especially true in view of the fact that the forwards will repeat the HIA numerous times during the match. Backs seem to spend more or less 3.2 sec on average on HIA at a time during a match, while their rest periods are 5.5 to 21.8 times (±17.6 to 69.8 sec) more than their working periods. From these findings it is therefore clear that backs would also primarily depend on the anaerobic lactic system as the primary contributor to energy after the first high-intensity period.

To date, research has provided several reasons for the differences between the work:rest ratios between the two positional groups. Duthie *et al.* (2003:983) contend that the difference in the nature of the game between forwards and backline players, gives rise to different physiological demands. For example, forwards are more engaged in rucks and mauls as well as scrums (i.e. static exertion types of activities) than the backs.

From the tabulated results it would seem that the average work:rest ratio of rugby matches has declined steadily from 1996/1997 (1:14.4) (Deutsch *et al.*, 2007:467) to 2009/10 (1:5) (Austin *et al.*, 2010:259). These findings suggest that players are currently performing more work interspersed with less rest periods during matches, compared to players that competed in rugby 12 to13 years ago. One of the factors that contributed to the change in work:rest ratios among different positional groups is the number of rule changes that the International Rugby Board (IRB) had introduced in 1999 to improve the safety and competitiveness of rugby union. These rule changes included changes to improve recycling at the breakdowns and the turnovers at loose scrums and to improve lifting during line-outs (Williams *et al.,* 2005:8). Furthermore, a study by Williams *et al.* (2005:7), in which games played in the Six Nations, Tri Nations, European Cup and Super 12 competitions during a five-year period (1998-2003) were investigated, reported a significant increase in game time from 1998 (1 min 27 sec) to 2003 (90 min 52 sec). With regard to ball in play time there was a significant increase from 1999 to 2000 (32 min 37 sec) with a decrease from 2000 to 2001 (31 min 34 sec) and a further increase from 2002 to 2003 (33 min 16 sec) (Williams *et al.*, 2005:9). The increased total game and ball in play time are due to rule changes which improved continuity (Williams *et al.*, 2005:9). Since 2003, other minor rule changes have also been made, but the possible effects of these rule changes on the game have not yet been studied. Thomas (2006:29) points out that the modern game is quicker; players are stronger and faster, contact is more aggressive and physical, and skill levels are more advanced. All of these factors may also give rise to shorter work:rest ratios during rugby matches than matches played a decade or more ago.

2.3.2 Shortcomings with regard to the use of time-motion analysis (TMA) for determining the demands of rugby union games

In spite of the fact that research, with regard to the movement analysis of rugby is important (especially for the coaching staff and players), several shortcomings with regard to the use of TMA for analysing rugby games have been identified. Firstly, this method can be very time consuming when each of the fifteen players have to be monitored for the duration of an entire match over a period of several matches (Hughes & Franks, 2009:73). This fact was also accentuated by O'Donoghue (2008:203) who showed that every minute of play takes more or less 30 minutes to analyse. Given that there are 15 players in a team and 80 minutes of match time this amounts to an enormous time-taxing task (roughly adding up to 36 000 minutes or 600 hours for one single match). Secondly, the validity of TMA can be questioned due to simplification of movement patterns into categories while actual play involves the combination of dynamic tasks, skills and tactics, which are not considered (Duthie *et al.*, 2003:983). Duthie *et al*. (2003:283) studied the reliability of video-based TMA by evaluating the reliability of the TMA results when the same video footage was analysed by the same individual observer a month after the original analysis. The reliability of the results with regard to the total time spent on individual movements (walking, standing, jogging, striding, sprinting and static exertion) and the mean duration of the individual movements were shown to be moderately reliable, whereas the frequency of individual movements were poorly reliable. Therefore Duthie *et al*. (2003:283) concluded that TMA is prone to measurement errors due to the subjectivity of the observations. Fourthly, TMA is limited in its ability to assess the specific demands of certain activities. For example, shuffling is usually categorised as a high-intensity movement, but could also be performed at low speeds, which can influence the energy cost of the movement in such a way that it should rather be categorised as a low-intensity movement (O'Donoghue, 2008:205). Fifthly, the indirect work method used in TMA for determining the distances travelled, the time engaged in different activities and the frequency of movement occurrences during a match may also lead to an underestimation of the total demands of match-play (Nicholas, 1997:379). In this regard, Reilly (cited in Nicholas, 1997:379) also observed that players required additional energy to accelerate, decelerate, run forward or laterally, for jumping, pushing, tackling and other match-related activities that are not always considered when the TMA results are conveyed.

One of the most effective tracking systems on the market is the Prozone system that tracks movements of the ball, players and referees automatically by making use of 6 fixed video cameras mounted in such a way that it covers the entire playing area (O'Donoghue, 2008:198). The requirement for 6 video cameras can, however cause practical and logistical problems when matches played at smaller venues need to be analysed. Usually these venues do not have proper stands or pavilions to which the different cameras can be mounted. The Prozone system is also too expensive for the general rugby-playing fraternity to purchase.

In view of the above-mentioned shortcomings with regard to the use of TMA for determining the match demands of rugby union, the emergence of global positioning systems (GPS) that may enable researchers to make more accurate analyses of rugby matches has come to the attention of researchers and sport-related practitioners alike.

2.4 <u>The use of global positioning systems (GPS) for analysing rugby union games</u>

The introduction of GPS technology has enabled coaches to gain specific information on the distances covered at different speeds (high and low-intensity velocities) during matches (Gabbet, 2010:1321). GPS technology therefore has numerous applications in sport, especially where the need arises to track team sport players' movements during matches (Ruddock, 2010). GPS equipment is also portable and has the potential to deliver real-time data (Ruddock, 2010). Furthermore, GPS systems that have been developed for use among sports teams have demonstrated an acceptable level of accuracy and validity (Ruddock, 2010). The reliability and validity of GPS devices are especially high in situations where the total distance covered during longer duration training drills and games needs to be determined (Jennings *et al*., 2010:336). However, in a study on energy expenditure of Australian football players, Aughy (2010:395) preferred a 5Hz GPS system to the 1Hz system (logging on 5 times a second *versus* once every second), due to higher accuracy, especially when measuring velocities.

2.4.1 Results of GPS analysis on rugby union match play

Only six studies (Deutsch *et al*., 1998:561; Hartwig *et al.*, 2006:16; Tucker, 2010; Venter *et al.*, 2011:5; Suárez-Arrones *et al.*, 2012:77) could be found that made use of GPS analysis to investigate rugby union match characteristics. Of these six studies, 3 (Deutsch, Hartwig and Venter) were done on junior rugby and will be discussed under the results of junior rugby analysis (paragraph 3.1).

The findings on GPS tracking in Table 11 will be discussed by comparing it with TMA results as portrayed in Tables 1 to 9. Tucker (2010) reported much higher values for the percentage of time spent standing still (70%) during match play, than previous TMA-related studies that reported values between 30.8% and 51% (Duthie *et al.*, 2005:527; Deutsch *et al.*, 2007:465; Roberts *et al.*, 2008:829). With regard to the percentage of time spent jogging Tucker (2010) (25%) showed similarities to the reported values of Deutsch *et al.* (2007:465), Duthie *et al.* (2005:527) and Roberts *et al.* (2008:829) with values ranging between 17% and 23% of the total match time. The results for the percentage of time spent sprinting revealed notably higher values (5%) in the GPS-related study of Tucker (2010) than all TMA-related studies where values ranged between 0.4% and 1.9% (Duthie *et al.*, 2005:527; Deutsch *et al.*, 2007:465; Roberts *et al.*, 2008:829).

Table 11: Results of studies which reported on the GPS match analysis in rugby union

References	Population	Forwards	Backs	Average
Total distance (averages) covered during match (m)				
Suárez-Arrones *et al.* (2012:77)	Spanish elite	5853	6471	6162
Tucker (2010)	Super 14 (2009/2010)	5000-7000	7000-7700	6000-7000
Percentage of total match time spent standing still (%)				
Tucker (2010)	Super 14 (2009/2010	65.0	75.0	70.0
Percentage of total match time spent jogging (%)				
Tucker (2010)	Super 14 (2009/2010)	-	-	25.0
Percentage of total match time spent sprinting (%)				
Tucker (2010)	Super 14 (2009/2010)	-	-	5.0
Average work:rest ratio for the activities performed during the match				
Suárez-Arrones *et al.* (2012:77)	Spanish elite	-	-	1:0.8
Tucker (2010)	Super 14 (2009/2010)	-	-	1:5
Percentage of total match time spent in LIA (%)				
Tucker (2010)	Super 14 (2009/2010)	-	-	95
Percentage of total match time spent in HIA (%)				
Tucker (2010)	Super 14 (2009/2010	-	-	5

2.4.2 Shortcomings with regard to the use of GPS for determining the demands of rugby union games

Like automated tracking devises, GPS systems are costly and no low-cost GPS units or software designed are available for use in team sports (Ruddock, 2010). Despite the fact that GPS devices have been shown to be reliable and valid for measuring total distances during longer duration activities, research showed that GPS devices cannot be used to measure brief, high-intensity sprints, or slow and fast accelerations over distances of less than 20 m, regardless of sampling rate (Jennings *et al.*, 2010:336). Coutts and Duffield (2010:133) supported this finding by concluding that although the accuracy and reliability level of GPS devices are acceptable for total distance and peak speeds during high-intensity intermittent exercise, it may not provide reliable measures for higher intensity activities. A study of Barbero-Álvarez *et al.* (2010:235) found that GPS devices are sensitive enough to detect relatively small changes in serial measurements of repeated sprint performance when completed over distances of more than 30 m – which still leaves one with a problem regarding repeated sprinting bouts of much shorter distances which are most commonly found in rugby union (average duration between 1.4 and 2.5 sec). Furthermore, Gray *et al.* (2010:359) pointed out that the accuracy and reliability of distance and velocity-derived GPS data still need to be determined for highly specific game-related activities. Therefore, Gray *et al*. (2010:359) concluded that only GPS data that describe changes in velocity during repeated sprints followed by subsequent recovery periods can be used to monitor workloads of both competitions and training.

2.5 <u>The use of blood lactate values for analysing rugby union matches</u>

Nowadays, blood lactate diagnostics serve as a standard element of exercise testing in top-class athletes as well as for commercial leisure exercise programmes (Beneke *et al*., 2011:8). The blood lactate concentration is sensitive to changes in exercise intensity and/or exercise duration (Beneke *et al*., 2011:8). Players' blood lactate values can also be used for determining the energy contribution of the anaerobic glycolytic pathway (Deutsch *et al.*, 1998:562). Furthermore, the blood lactate threshold is generally accepted to be a performance indicator in sport (Beneke *et al*., 2011:10) due to the fact that, amongst other things, a rapid accumulation of blood lactate takes place above the lactate threshold level (Mahon *et al.*, 1997:1332). The blood lactate level of an athlete is determined by obtaining a blood sample which is collected in a heparinised capillary tube by means of the finger prick procedure and by analysing the obtained sample (Mahon *et al.*, 1997:1333). Blood samples can also be obtained from the earlobe (Deutsch *et al*, 1998:563; Matthew & Delextrat, 2009:815). This technique has also been applied for determining the exercise intensities of rugby union games, and the results of these studies will be discussed in the subsequent section.

2.5.1 <u>The results of blood lactate analysis on rugby union match play</u>

Table 12 presents the blood lactate values of rugby players obtained during or after match play.

Table 12: Literature reported blood lactate values of rugby union players for periods during stoppages in match play or after matches

References	Timing of measurement	Population	Forwards	Backs	Average
Average blood lactate values (mmol/L)					
Docherty *et al.*(1988:269)	5-10 Min post match	International (n=11)	-	-	2.8
Deutsch *et al.*(1998:568)	Penalty kick or injury stoppages	Under-19 (n=24)	6.6	5.1	5.9-

Deutsch *et al.* (1998:568) reported higher blood lactate concentration values for the forwards (6.6 mmol/L) than the backs (5.1 mmol/L). These blood lactate concentrations implicate the considerable demands that are placed on the anaerobic metabolism of rugby players. The blood lactate-related results would also suggest that the forwards depend more on the anaerobic lactic glycolytic energy system and perform more anaerobic-related activities on the field than the backs. An older study by Docherty *et al.* (1988:269) obtained much lower average blood lactate concentration values in their study of international rugby players with values ranging between 2.8 and 3.8 mmol/L.

Previous research has shown that a blood lactate concentration of more or less 4 mmol/L corresponds to the anaerobic threshold of subjects, though certain individuals may reach the anaerobic threshold at lower or higher blood lactate concentrations (3-6 mmol/L) (Jansen, 2001:111). Within this contention it can therefore be postulated that the low blood lactate concentrations (< 4mmol/L), reported for rugby players by Docherty *et al.* (1988:269), would indicate that the aerobic energy system is the primary energy provider during a rugby match. The above-mentioned results must, however, be interpreted with caution due to certain limitations and shortcomings with regard to the use of blood lactate concentration values for analysing and describing the demands of rugby matches. Furthermore, it must also be emphasized that all of the studies that have reported on the blood lactate concentration values of rugby players were published before 1999 when new rule changes with regard to rugby union were implemented. As been mentioned before, the new rule changes had an effect on the characteristics of rugby match play, which may possibly also lead to different blood lactate values for rugby players.

2.5.2 <u>Shortcomings with regard to the use of blood lactate analysis for determining the demands of rugby union matches</u>

For the following reasons the validity and accuracy of the blood lactate concentration values obtained during rugby matches can be questioned: Blood lactate samples can only be taken during stoppages in play (for example at half time or during the treatment of injuries) or at the end of the match (Nicholas, 1997:380), which will generally not give researchers a true representation of the overall demands of the match. This is especially true in match situations where players perform numerous bouts of high-intensity work. If the blood sampling takes place a few minutes after the high-intensity bouts have taken place, the blood lactate will be metabolised and will not give a true representation of the overall demands of the game (Duthie *et al.,* 2003:986). Much lower blood lactate concentration values will therefore be measured and will lead to an underestimation of the importance of the anaerobic glycolytic energy system during a rugby match (Nicholas, 1997:380). This fact is especially relevant in cases where blood lactate concentration values are obtained a few minutes after the match as in the study of Docherty *et al.* (1988:269). Furthermore, Spurway and Jones (2008:118) argued that a comparison of the blood lactate concentration values between two individuals will possibly lead to discrepancies in the interpretation of these values in view of the fact that the rate of lactate clearance from the muscle to the blood differs from one person to a next. It is therefore possible that a lower blood lactate concentration value for one person compared to another is the result of a faster lactate clearance rate and not due to the production of more blood lactate as a result of more anaerobic glycolytic activity in the muscle.

In view of these issues, it would be advisable to also use other methods in addition to blood lactate analysis, in order to interpret TMA results more accurately.

2.6 The use of heart rate values for analysing rugby union matches

Heart rate (HR) has become the most commonly used method for determining exercise intensities of on-field activities because of the emergence of portable, wireless systems that are user friendly and make heart rate easy to monitor (Achten & Jeukendrup, 2003:525). HR profiles can also be used, amongst other things, for determining the duration of periods spent at different exercise intensities during a rugby match (Deutsch *et al.*, 1998:562).

2.6.1 The results of heart rate analysis on rugby union match play

Only one study could be found that has made use of HR measurements for analysing the demands of rugby matches. In this regard, Deutsch *et al*. (1998:563) categorised HR into the mentioned intensity zones for use in analysing the Australian u/19 Colts' rugby matches: maximal (>95% of HR_{max}), supra-threshold (85-95% of HR_{max}), anaerobic threshold (75-85% of HR_{max}) and sub-threshold intensity zones (< 75% of HR_{max}) where maximal heart rate (HR_{max}) was the highest HR measured during a match. They revealed that the tight five (58.4%) and back-row forwards (56.2%) spend more time in high-intensity activities (>85% of HR_{max}) when heart rate values were analysed, than the inside (40.5%) and outside backs (33.9%). Furthermore, the results showed that the forwards spend up to 20% of the match time in the heart rate zone above 95% of the HR_{max}, compared to the backs that spend most of the match time in the low (< 75% of HR_{max}) or moderate-intensity zones (75-85% of HR_{max}) (Deutsch *et al.*, 1998:567). As mentioned before, these results also suggest that the demands of forward play are much higher than those of backline play.

2.6.2 Shortcomings with regard to the use of heart rate measurements for determining the demands of rugby union matches

Heart rate can be regarded as an accurate indicator of exercise intensity for team sport participants, although dehydration, day to day variability and ambient temperature need to be considered when interpreting HR measurements (Achten & Jeukendrup, 2003:518). Furthermore, it is possible that heart transmitter belts which are fastened to the chest of players may move or loosen due to the contact nature of certain team sports such as rugby. These changes in the position of the belt may possibly influence the HR values stored on or transmitted to the computer (Deutsch *et al.*, 1998:563). Coutts *et al.* (2003:102) stated that the nature of contact sport (in this case rugby league) can also affect the HR-$\dot{V}O_2$-relationship (elevated beyond the normal relationship), with factors including physical contact, isometric contractions during scrums (in rugby union also including the on the ball activities such as rucks, mauls and tackles) as well as thermal and emotional stress.

2.7 The combined use of different methods for analysing rugby union matches

Due to the shortcomings of only using one method for analysing the demands of rugby union matches, the use of a combination of methods for obtaining more accurate and reliable data have become more common. In this regard, Deutsch *et al.* (1998:561) used a combination of heart rate, blood lactate and time-motion analysis for analysing the matches of under-19 elite rugby union players. The main focus of the study was to establish position-specific profiles for this group of players. The results of this study showed that forwards spend 20% of match play time at 95% of the HR_{max} while the backs spend most of the time at 75-85% of HR_{max} (Deutsch *et al.*, 1998:567). These results do again suggest that the forwards overall performed more high-intensity activities than the back line players. Coutts *et al.* (2003:97) used the heart rate and oxygen uptake ($\dot{V}O_2$) values concurrently, as well as the blood lactate values of semi-professional rugby league players to study the energy expenditure during match play. Each player's maximal oxygen uptake ($\dot{V}O_{2max}$) was determined by using an incremental treadmill test, which was performed a week after the match (Coutts *et al.*, 2003:99). The individual energy expenditure was then estimated from the heart rate-$\dot{V}O_{2max}$ relationship (Coutts *et al.*, 2003:99). HR and $\dot{V}O_2$ are linearly related over a wide range of sub-maximal intensities and could therefore be used to accurately determine the on-field intensities or energy expenditure of rugby players (Achten & Jeukendrup, 2003:526). Also, by determining the HR-$\dot{V}O_2$-relationship, the HR can be used to predict the $\dot{V}O_2$ of players (Achten & Jeukendrup, 2003:528). The recorded individual match heart rate values can also be expressed as a percentage of the individual's $\dot{V}O_{2max}$ test-related maximum HR value (Coutts *et al.*, 2003:99). Coutts *et al*. (2003:98) also used the last-mentioned method to categorize the recorded match HR into the following zones: low-intensity zone = <70% of HR_{max}; moderate-intensity zone = 70-85% HR_{max} and high-intensity zone = >85% HR_{max}.

A more accurate way to measure exercise intensities during the execution of different movement patterns or activities is by determining the heart rates at two definite gas exchange points for each individual by means of a cardio respiratory exercise test (Sparks, 2010:32). The ventilatory threshold (VT) and respiratory compensation point (RCP) of each individual is predetermined in a laboratory by using the direct measurement of $\dot{V}O_2$ by indirect calorimetry and specifically by open-circuit spirometry during an incremental treadmill test (Esteve-Lanao *et al.,* 2005:498). The criteria for determining the VT is an increase in the equivalent for oxygen consumption ($\dot{V}_E/\dot{V}O_2$) with no increase in the equivalent for carbon dioxide production ($\dot{V}_E/\dot{V}CO_2$) and departure from the linearity of $\dot{V}_E$ (Chicharro *et al*., 2000:452). RCP is determined to be the point which corresponds to an increase in both the $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$ (Rodriguez-Marroyo *et al.*, 2007:180). By determining the VT and RCP, three exercise-intensity zones can be identified, namely: (1) The low-intensity zone = exercise performed at heart rates that correspond to the intensities below VT; (2) The moderate-intensity zone = exercise performed at heart rates that correspond to the intensities between VT and RCP and (3) the high-intensity zone = exercise performed at heart rates that correspond to the intensities above RCP (Chicharro *et al.*, 2000:451; Esteve-Lanao *et al.,* 2005:496; Seiler & Kjerland, 2006:49; Rodriguez-Marroyo *et al.,* 2007:180).

Various authors have made use of this method for analysing the intensity categories of different individual sports to quantify the relationship between training load and competition performance of endurance runners (Esteve-Lanao *et al.,* 2005:496); to determine the daily distribution of training intensities in endurance athletes (& Kjerland, 2006:49) and to analyse and compare the workload of professional cyclists over 5-day, 8-day and 21-day races (Rodriquez-Marroyo *et al.*, 2007:180). However, only one study could be found that has investigated the use of this method for determining the match demands of rugby union players (Sparks, 2010). The results of this study will be discussed under the next heading due to the fact that it is the first study to have used heart rate and graded maximal test values concurrently for determining the match intensities of rugby players.

2.7.1 <u>The use of heart rates and the gas-exchange values obtained during an incrementally graded running test for analysing rugby union match play</u>

Sparks (2010) did a study on senior 1^{st} and 2^{nd} team university level players by means of heart rate and graded maximal test value analyses. Three rugby matches were analysed by subjecting the players to an incremental test to exhaustion at least two weeks before or after each match (Sparks, 2010:32). The heart rate intensity zones were categorized as follow: low-intensity zone – 141 to 152 bpm (76.2% to 82% HR_{max}); moderate-intensity zone - 153 to 169 bpm (82.7% to 91.4% HR_{max}) and high-intensity zone – 170 to 182 bpm (91.9% to 100% HR_{max}) (Sparks, 2010:32). The results of this study are presented in Table 13.

Table 13: Results with regard to the time and percentage of time spent in each intensity zone during rugby matches by university-level players

References	Intensity zones	Forwards	Backs	Average
Percentage of time spent in each intensity zone during a match (%)				
Sparks (2010:61)	Low-intensity zone	11.3	34.2	22.6
	Moderate-intensity zone	34.1	33.1	33.6
	High-intensity zone	54.6	32.7	43.7

From Table 13 it is apparent that players spend the majority of time during matches in the high-intensity zone. The backs spend more of the total match time in the low-intensity zone during matches (34.2% *versus* 11.3%), and less time in the high-intensity zone (54.6% *versus* 32.7%) than the forwards. The amount of time both positional groups spend in the high-intensity zone during match play was much higher than the previously reported values of TMA-related studies In this regard only Austin *et al.* (2011:261) reported a value of above 30% (33.5%) for the total match time spent on HIA when making use of TMA. Possible reasons for the differences in the percentage of time spent in each intensity zone during rugby matches between this and other studies are (Sparks, 2010:44): A more accurate reflection of the physical demands placed on players during match play is obtained when heart rate values are used for analysing rugby matches. Heart rates usually take a few seconds to decrease back to the moderate-intensity range, which will probably increase the period players spend in the high-intensity heart rate zone. Previous studies that reported shorter time periods in the high-intensity zone made use of TMA where high-intensity activities were timed as it took place and the time watch stopped as soon as the activity had reached its end. This will definitely lead to lower values than those of studies where the heart rate-related analysing method was used.

3. The analyses of junior rugby games

A scarcity exists with regard to the number of publications that have focussed on the match analyses of young rugby players (schoolboys, juniors or adolescents). In this regard one study by Deutsch *et al*. (1998:561) focussed on the heart rate, blood lactate and kinematic data of elite under-19 rugby union players during match play. More recent studies by Hartwig and his team of researchers (Hartwig *et al*., 2006:16; Hartwig *et al*., 2008:94; Hartwig *et al*., 2009:1087) compared the match characteristics of twelve 16-year-old boys over a period of 11 rugby matches, with their training characteristics. Take note that these studies were summarized in a PhD thesis (Hartwig *et al*., 2009:190) and in the further discussions reference to it will be only the 2009 publication. The results of the last-mentioned studies will be discussed in the subsequent section.

3.1 <u>The results of junior rugby union match and training analyses</u>

Deutsch *et al.* (1998:566) used GPS technology on under-19 elite rugby union players for match analysis for determining the time spent standing still, walking, jogging, striding and sprinting. Venter *et al.* (2011:5) used the same method on under-19 provincial players, but adding maximal sprinting to the classifications. Hartwig *et al*. (2009:194) used GPS technology on 16-year-old rugby union players for determining the same variables and for analysing the total distances covered, the average speed of different movement patterns and the average time sprinting during rugby matches. The results of these studies are presented in Table 14.

Table 14: Percentage (%) of match time spent in different movement patterns

Reference	Forwards	Backs	Average
Standing still			
Deutsch *et al.* (1998:566)	45.9	40.8	43.4
Hartwig *et al.* (2009:194)	44.5	32.7	38
Venter *et al.* (2011:5)	22.3	20.8	21.6
Walking			
Deutsch *et al.* (1998:566)	15.4	27.3	21.3
Hartwig *et al.* (2009:194)	35.5	48.8	42
Venter *et al.* (2011:5)	44.5	60.3	50.7
Jogging			
Deutsch *et al.* (1998:566)	20.6	18.7	19.6
Hartwig *et al.* (2009:194)	14.5	13.6	14
Venter *et al.* (2011:5)	24.9	17.8	21.3
Striding			
Deutsch *et al.* (1998:566)	1.85	2.7	2.03
Hartwig *et al.* (2009:194)	3.6	3.1	3.8
Venter *et al.* (2011:5)	7.8	4.5	6.2
Sprinting			
Deutsch *et al.* (1998:566)	0.4	1.05	0.07
Hartwig *et al.* (2009:194)	0.9	1.3	1.1
Venter *et al.* (2011:5)	0.4	0.9	0.6
Maximum Sprint			
Venter *et al.* (2011:5)	0.06	0.06	0.06
Static exertion			
Deutsch *et al.* (1998:566)	13.9	1.3	7.6

Obvious similarities occur between the total match time spent standing still between the forwards of the two age groups as found by Deutsch (1998:566) and Hartwig (2009:194) (u/19 = 45.9% and u/16 = 44.5%). Venter's results differ vastly with a value of 22.3%. The 1998 u/19 backs spend more time standing still than the 2009 u/16 players (u/19 = 40.8% and u/16 = 32.7%), with the 2011 u/19's the least (20.8%). Similar differences were found for the groups' averages for standing still (1998 u/19 = 43.8%; u/16 = 38% and 2010 u/19 21.6%). It is thus obvious that both the forwards and backs in Venter's study spent far less time standing still than the 1998 u/19 and 2009 u/16 players. The 1998 u/19 players walked far less (15.4% forwards; 27.3% backs and 21.3% on average) than the 2009 u/16 players (15.4% forwards; 48.4% backs and 42% on average) with the 2011 u/19 players having spent more time than both the other groups of players walking (44.5% forwards; 60.3% backs and 50.7% on average). The 1998 u/19 players (20.6% forwards; 18.7% backs and 19.65% on average) seemed to jog more or less the same as the 2011 u/19 players (24.9% forwards; 17.8% backs and 21.3% on average). Hartwig's 2009 u/16 players jogged less than both the u/19 groups (14.5% forwards; 13.6% backs and 14% on average). Although all three age groups' average time spent on striding was low (below 8%) a difference was observed for the forwards between the groups (1998 u/19 = 1.85%, u/16 = 3.6% and 2011 u/19 7.8%). The backs spent similar average times on striding (u/19 = 2.7% and u/16 = 3.1%) between the 1998 and 2009 groups, with the 2010 u/19 players slightly higher on 4.5%. The averages for the 2009 u/16 forwards and the whole group of players were much higher than those of the 1998 u/19 groups of players (u/16 = 3.6% and 3.8% *versus* 1.85% and 2.03% for u/19). All three the values of the 2011 u/19 players were noticeably the highest (7.8% forwards, 4.5% backs and 6.2% on average). Venter (2011:5) also found that the forwards spent almost double the time striding (7.8%) as opposed to the backs' 4.5%. The average times spent sprinting showed more or less similar values for the three groups of players, although the 2009 u/16 players (0.9% forwards; 1.3% backs and 1.1% on average) obtained slightly higher values than both the 1998 u/19 players (0.4% forwards; 1.05% backs and 0.7% on average) and 2010 u/19 players (0.4% forwards; 0.9% backs and 0.6% on average).

3.2 Differences between the junior and senior rugby union match rules

A number or rule differences exist between senior and junior rugby union. In this regard the International Rugby Board (IRB) laws (IRB, 2011:165) state that a match for u/19 players comprises two halves of 35 minutes each compared to a match for senior players which comprises two halves of 40 minutes each. A further law variation exists for younger rugby union players with regard to the length of the match, with the match length for the under-14, under-15 and under-16 age groups, which is supposed to be 50 minutes in total (two 25 minute halves), with no injury/extra time allowed (Van Heerden, 2011). Law variations that apply to different facets of u/19 rugby union matches state that the scrum must not be allowed to be pushed further than 1.5 meters towards the opponents' goal line and has to be reset if it wheels more than 45º (IRB, 2011:167). This differs from the scrum rule that applies to the senior players that are allowed to obtain an unlimited scrumming distance when pushing and wheeling the scrum to 90º. Another rule variation that applies to junior rugby scrums is that the team that was in possession of the ball (when the scrum wheeled through 45º) retains the throw-in when the scrum is reset, whereas the opposing team receives the throw-in for the reset scrum in senior rugby (IRB, 2011:167). Additionally, the ball may be kept at the back of the scrum during a forward movement in senior rugby, but at schoolboy level the ball must be retrieved/released as soon as the team in possession has control of the ball (IRB, 2011:167).

3.3 Differences between the match play characteristics of junior and senior rugby matches

In the light of the above-mentioned differences with regard to the rules that apply to junior and senior rugby match play, the results of studies with regard to the match analysis of under-16, under-19 and senior (super 12 and English elite club) rugby union players are shown in Tables 15 and 16.

Table 15: The difference between total distances covered during a rugby union match between junior and senior rugby players.

Average distance covered (km)		
Junior rugby union		
Deutsch *et al.* (1998:561) under-19 elite	Matches	4800m
Hartwig *et al.* (2006:16) under-16	Matches	5800m
Senior rugby union		
Roberts *et al.* (2008:828) 2002-2004 English Premier	Matches	5859.7m
Austin (2011:259) Super 14 (2008/2009)	Matches	5609.8m

It is notable that Deutsch *et al.* (1998:561) found that the total distances covered during a rugby union match (4800 m) are far less than those of Hartwig *et al.* (2006:16) that reported an average distance of 5 800 m. The total distance found by Hartwig *et al.* (2006:32) (5800 m) is more comparable to that of both Roberts *et al.* (2008:828 - 5859.7 m) and Austin (2011:259 – 5 609.8 m).

Studies that investigated the percentages of time spent during junior and senior rugby union matches in LIA and HIA are presented in Table 16.

The results with regard to the percentage of time spent during rugby matches in LIA are very similar between junior and senior rugby, with studies on junior rugby matches obtaining average values of between 86.5% (Deutsch *et al.*, 1998:566) and 92% (Hartwig *et al.*, 2006:16) compared to studies on senior rugby matches that reported values of between 88.4% and 95% (Duthie *et al.*, 2003:984; Duthie *et al.*, 2005:527; Deutsch *et al.,* 2007:465; Roberts *et al.*, 2008:829; Tucker, 2010). However, a more recent study by Austin *et al.* (2011:261) on Super 14 rugby matches revealed a much lower percentage of time spent in LIA (60.7%) than that of junior rugby matches.

Table 16: Comparisons between the percentages of time spent during rugby matches in LIA and HIA between junior and senior rugby

References	Forwards	Backs	Average
Total LIA			
Senior rugby matches			
Deutsch *et al*. (2007:465) 1996/1997 Super 12	86.6	90.8	88.7
Duthie *et al.* (2005:527) 2001/2002 Super 12	88.0	95.0	91.5
Duthie *et al*. (2003:984) Club to International	-	-	85.0
Austin *et al*. (2011:261) Super 14	64.0	57.0	60.7
Roberts *et al*. (2008:829) English premier	84.5	92.4	88.4
Tucker (2010) Super 14 (2009/2010)	-	-	95.0
Junior rugby matches			
Deutsch *et al.* (1998:566)	83.7	89.5	86.5
Hartwig *et al*. (2009:194)	94.5	95.1	94.6
Total HIA			
Senior rugby matches			
Deutsch *et al.* (2007:465) 1996/1997 Super 12	5.3	5.2	5.3
Duthie *et al.* (2005:527) 2001/2002 Super 12	13.9	5.1	8.7
Duthie *et al.* (2003:984) Club to International	-	-	15.0
Austin *et al.* (2011:261) Super 14	31.5	35.5	33.5
Roberts *et al.* (2008:829) English premier	15.5	7.9	11.8
Tucker (2010) Super 14 (2009/2010)	-	-	5.0
Junior rugby matches			
Deutsch *et al.* (1998:561) under-19 elite	30.3	11.8	18.8
Hartwig *et al.* (2006:16) under-16	4.5	4.4	4.5

A comparison between the percentage of time spent in HIA during junior and senior rugby matches showed no fixed pattern, with some studies reporting much higher (11.8-33.5%; Duthie *et al.*, 2003:984; Roberts *et al*., 2008:829; Austin *et al.*, 2011:261), more or less the same (8.7%) (Duthie *et al.*, 2005:527) or lower values (5% - 5.3%) (Deutsch *et al.,* 2007:465; Tucker, 2010) for senior rugby matches than junior rugby matches (18.8%) (Deutsch *et al.*, 1998:566) and 4.5% (Hartwig *et al.*, 2006:16).

The above-mentioned rule differences that apply to junior and senior rugby matches may possibly explain some of the differences in the match analyses results between these two groups of players. For example, the differences in the duration of matches between the two mentioned populations as well as the differences in the execution of scrums may increase the demands of senior rugby match play when compared to those of junior rugby match play.

4. Conclusions

Performance analysis can enable coaches, sport scientists and other sport-related professionals to understand the specific demands of rugby union better in order to plan and implement the most effective training programs and testing procedures for rugby players. In view of the last-mentioned facts, the aims of this literature review were to firstly present the results of research that have investigated the use of different match analyses methods for determining the demands of senior and junior rugby union matches; secondly, to highlight the shortcomings with regard to the use of each of the methods; and thirdly, to explain the rule differences between senior and junior rugby and lastly, to compare the match analyses results between each of the methods regarding senior and junior matches.

Several methods for use in the match analyses of rugby union were identified, which included the following: notational analysis, time-motion analyses, GPS analyses, blood lactate monitoring, and heart rate recording and analyses as well as the combined use of heart rates and graded maximal test values.

The results of TMA studies on rugby union (elite provincial level) showed that 57% to 95% of game time was spent on low-intensity activities (LIA) and high-intensity activities had increased from as low as 5.3% in 1996 to 33.5% of total match time in 2011. GPS monitoring showed the total percentages of match time spent in LIA to be 92-95% and in HIA 5-9%. One study using heart rate measurements found that the forwards had spent 57.3% of the total match time on HIA (above 95% of HRmax) and the backs 37% of the total match time on HIA. These findings did not correlate with the GPS-related studies but did show similarities to the results of TMA studies. Studies that measured the blood lactate levels of players reported blood lactate values of above the lactate threshold (LT) levels for both forwards and backs (with LT assumed to be at an average of 4 mmol/L). These results suggested that rugby union is more anaerobic in nature. However, previous findings reported average blood lactate levels for forwards and backs alike to be below the LT levels, accentuating the more aerobic nature of the game. In a study in which a combination of methods was used it was observed that the forwards had spent 20% of the match time at 95% of the HR_{max} in HIA, whereas the backs had spent most of the match time at 75% to 85% of the HR_{max}. One study that used heart rates and graded maximal test values concurrently divided match intensities into low (LIZ), moderate (MIZ) and high-intensity zones (HIZ). Results of this study showed that the forwards had spent 11.3% in the LIZ and the backs 33.6%; the forwards had spent 34.1% of the total match time in the MIZ with the backs 33.1%; and the forwards had spent 54.6% in the HIZ with the backs 32.7%.

Each of the TMA, GPS, HR and blood lactate measuring methods has drawbacks, with TMA only measuring visible actions, incorrectly categorising real (static) exertion types of activities and being prone to measurement errors due to the subjectivity of the observations. GPS measures speed of movement and accurately determines total distance covered during match play but do not reflect the actual exertion levels of players and may be inaccurate when measuring the speed of activities executed over distances below 30 meters. Blood lactate can be regarded as a rather accurate method for identifying time periods when the exertion is above or below the lactate threshold level, but is only accurate for activities performed immediately before the measurement has taken place. All the investigations where blood lactate measurements of rugby players were thus far taken, the measurements were taken during stoppages in play which will not reflect the real physiological requirements of the rugby game. These limitations with regard to the application of heart rates, blood lactate and TMA for determining rugby game intensities have compelled researchers to also investigate the use of a combination of methods in order to increase the accuracy and validity of game analysis results.

However, most analyses of modern rugby union lead to the conclusion that the game is aerobic in nature due to longer periods of inactivity, stoppages and low-intensity activities observed during match play. This would justify the use of training programs that primarily focus on improving the aerobic capacity of rugby players. However, the intermittent nature of the game forces players to frequently repeat high-intensity bouts interrupted by periods of brief rest, which place a higher demand on the anaerobic energy systems. Usually, the high-intensity activities will utilise the short-term ATP/CP energy system, but due to the brief rest periods that do not allow the body to fully resynthesize the ATP/CP stores (3- 5 minutes), higher demands will be placed on the anaerobic lactic energy system. A good aerobic capacity will, however, be important for recovery between exercises (bouts) and/or training sessions (Chu, 2001:85). From the last-mentioned conclusions it can therefore be suggested that rugby training programs should primarily focus on developing the ATP/CP system and also on incorporating high-intensity medium-duration activities to briefly stress the anaerobic lactic system while simultaneously also taxing the aerobic energy systems of the players to enhance recovery during rest periods. These results can assist coaches and fitness personnel in establishing accurate conditioning programs.

Despite the amount of recent studies on rugby union match analysis, research focussing on the game analysis of junior rugby union is lacking, with only two authors that have reported the results of this group of players. These differences in the game analysis results between the two mentioned groups of players highlight the importance of discriminating between the match demands of junior and senior players. Rule differences which dictate a shorter total match length for junior rugby and shorter duration of and less taxing scrums for juniors stress the need for more rugby union match analysis studies on junior rugby players in order to more accurately determine the energy requirements and match demands of this group of players, so as to enable coaches and sport scientists to set more specific training guidelines.

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CHAPTER: 3

3 DETERMINING ADOLESCENT BOYS' RUGBY UNION GAME INTENSITIES USING HEART RATES AND GRADED MAXIMAL TEST VALUES

TITLE: DETERMINING ADOLESCENT BOYS' RUGBY UNION GAME INTENSITIES USING HEART RATES AND GRADED MAXIMAL TEST VALUES

RUNNING HEAD: THE DETERMINATION OF RUGBY UNION GAME INTENSITIES

LABORATORY: INSTITUTE FOR SPORT SCIENCE AND DEVELOPMENT, FNB NWU HIGH PERFORMANCE INSTITUTE OF SPORT, NORTH-WEST UNIVERSITY, POTCHEFSTROOM CAMPUS, POTCHEFSTROOM, SOUTH AFRICA

AUTHORS: FRANCOIS WILLEMSE & BEN COETZEE

DEPARTMENT: PHYSICAL ACTIVITY, SPORT AND RECREATION FOCUS AREA, FACULTY OF HEALTH SCIENCES, NORTH-WEST UNIVERSITY, POTCHEFSTROOM CAMPUS, POTCHEFSTROOM, SOUTH AFRICA

CORRESPONDING AUTHOR:
FRANCOIS WILLEMSE
SCHOOL OF EDUCATION
INTERNAL BOX 539
FACULTY OF EDUCATION,
NORTH-WEST UNIVERSITY
POTCHEFSTROOM CAMPUS
POTCHEFSTROOM
2520
SOUTH AFRICA

TEL: +27 18 299 1914
FAX: +27 18 299 1716
E-MAIL: 10961542@nwu.ac.za

ABSTRACT

The purposes of the present study were to firstly, determine the heart rate and standard graded maximal oxygen uptake test values of u/15 high school rugby players; secondly, to determine the intensities of u/15 high school rugby union games when making use of heart rates and standard graded maximal oxygen uptake test values and lastly, to determine whether the absolute and relative total match time spent in each heart rate intensity zone during u/15 high school rugby games are significantly different when making use of heart rates and standard graded maximal oxygen uptake test values. Twenty-four u/15 rugby players performed a standard graded maximal oxygen uptake ($\dot{V}O_{2max}$) test to the point of exhaustion in the weeks between several rugby matches. The heart rates that corresponded to two definite gas exchange points, the ventilatory threshold (VT) and respiratory compensation point (RCP), were used to classify the heart rates into low, moderate and high-intensity zones. Telemetry enabled the researchers to determine the match heart rates and categorize it into the different zones. The heart rates for the three intensity zones were determined to be: <154.33 bpm (low intensity zone, LIZ), 154.33-184.35 bpm (moderate intensity zone, MIZ) and >184.35 bpm for the high intensity zone (HIZ). The players spent 56.34% of match time in the MIZ (27 min and 49 s), followed by the HIZ (10 min and 55 s, 23.03%) and the LIZ (9 min and 6 s, 19.95%). However, the average duration of low intensity bouts was higher (67 s) than the low (40 s) and high (39 s) intensity bouts, respectively. Lastly, significant differences were observed for all the above-mentioned values between the low and moderate intensity zones, as well as between the moderate and high intensity zones. Therefore, the use of heart rates and standard graded maximal oxygen uptake test values may provide a more accurate method for analysing the demand of adolescent rugby union matches. The results of this new analysing method seem to suggest that adolescent rugby union coaches and sport scientists need to focus more on moderate intensity activities that tax the aerobic energy systems for periods of 67 s at a time at a heart rate of more or less 78 to 93% of HR_{max} during training sessions.

KEY WORDS: rugby union, physiological demands, time-motion analysis, match play intensities, $\dot{V}O_{2max}$

INTRODUCTION

Since Rugby Union became a professional sport in 1995, rugby players have become highly paid professional athletes (28). Rugby administrators have also realized that it is essential to win more rugby matches in order to retain the interest of broadcasters, sponsors and the public so that more revenue can be generated (18). Therefore, a large amount of pressure is placed on players to win every match they play. This mentality of "winning is everything" has also been carried over to junior rugby where the majority of development programs for junior players are based on the content, practices and physiological make-up of elite senior players (11). However, according to Hartwig et al. (12), the volume of younger rugby players' sports participation (training and competition) needs to be monitored to determine the most appropriate workloads to ensure that future participation and performance are not compromised. In spite of researchers' recommendations, the physical demands of adolescent rugby union players are poorly documented, and there are no evidence-based strategies to monitor participation loads (12).

A number or rule differences exist between senior and junior rugby union (14) with regard to the duration of matches and the execution of scrums, which would suggest that the demands of senior rugby match play will be much higher than that of junior rugby match play. Only a few studies exist with regard to the match characteristics of adolescent rugby union players (u/19 players and younger). In this regard Deutsch et al. (8) and Venter et al. (27) used global positioning system (GPS) technology on under 19 elite rugby union players to determine the time spent standing still, walking, jogging, striding and sprinting. Hartwig et al. (13) used GPS technology on 16-year-old rugby union players to determine the same variables as well as to analyse the total distances covered, the average speed of different movement patterns and the average time spent sprinting during rugby matches. A comparison between the results of the last-mentioned studies and those of senior rugby players suggests that the percentage of time spent during rugby matches in low intensity activities such as standing still, walking and jogging are very similar between junior and senior rugby, with studies on junior rugby matches that obtained average values of 86.5% (8), 93.6% (27) and 94.8% (13) compared to studies on senior rugby matches that reported values of between 88.4 and 95% (9,10,11,19,26). A more recent study by

Austin et al. (1) on Super 14 rugby matches revealed a much lower percentage of time spent in low intensity activities (60.7%) than that of previous junior rugby match analysis-related studies. A comparison between the percentage of time spent in high intensity activities such as striding, sprinting and static exertion type of activities during junior and senior rugby matches showed no fixed pattern, with some studies reporting much higher (11.8-33.5%) (1,10,26), more or less similar (8.7%) (15) or lower values (5-5.3%) (9,26) for senior rugby matches than adolescent rugby matches (4.5%) (18) and (15.8%) (8).

Although the above-mentioned results do allow researchers and other sport-related professionals to determine the characteristics and demands of rugby union matches, the use of time-motion, blood lactate, heart rate and GPS analyses in the above-mentioned studies have been questioned due to certain limitations that have been identified (3,5,7,12,14,21). These limitations have compelled researchers to also investigate the use of a combination of methods in order to increase the accuracy and validity of game analysis results. A more accurate way of measuring exercise intensities during the execution of different movement patterns or activities is by determining the heart rates at two definite gas exchange points (ventilatory threshold (VT) and respiratory compensation point (RCP)) for each individual by means of a standard graded maximal oxygen uptake test (24). By determining the VT and RCP, three exercise intensity zones (low, medium and high) can be identified (4,20) and the percentage of time that the player spent in each intensity zone during a match, can be determined. In spite of the benefits that can be derived from the use of this technique, only one researcher made an attempt to use this technique to determine the game intensities of rugby union players (23).

From this above-mentioned study it was apparent that senior university-level players spent the majority of time during matches in the high-intensity zone (43.7%) and less time in the moderate (33.6%) and low intensity zones (22.6%) (23). These results were totally dissimilar to what previous researchers reported with regard to the percentage of time senior rugby players spent in the different intensity zones. In all other studies researchers found that players spent the majority of time in the low intensity zone or on low intensity activities (60.7% to 91.5%) compared to the percentage of time in the high intensity zone or on high intensity activities (5.3 to

33.5%) (1,11,12,13,19). According to Sparks and Coetzee (23), these differences may be attributed to the use of heart rates instead of movement speeds to determine the intensities of activities. Each player's heart rate intensity zones were also individually determined through the standard graded maximal oxygen uptake test which provided a more accurate reflection of the physical demands placed on each player during match play, compared to time motion analysis (23).

Therefore, in light of the above-mentioned research findings which suggest that the demands of rugby union games need to be quantified by making use of a combination of methods and that a scarcity exists with regard to the number of publications that have focussed on the match analyses of young rugby players, the purposes of the present study were firstly, to determine the heart rate and standard graded maximal oxygen uptake test values of u/15 high school rugby players; secondly, to determine the intensities of u/15 high school rugby union games when making use of heart rates and standard graded maximal oxygen uptake test values and lastly, to determine whether the absolute and relative total match time spent in each heart rate intensity zone during u/15 high school rugby games are significantly different when making use of heart rates and standard graded maximal oxygen uptake test values. Results of this study could possibly enable future coaches, rugby players and sport scientists of u/15 high school rugby teams to compile conditioning programs specifically in accordance with the demands of rugby games.

METHOD

Experimental Approach to the Problem

Due to the fact that no research exists that has made an attempt to use the above-mentioned technique to classify the different exercise intensity heart rates and to determine the game intensities of high school rugby union games, no hypothesis was set for the first purpose of the study. For the second purpose of the study the specific hypothesis under scrutiny was that u/15 high school rugby union games will be characterised by more low and moderate-intensity activities than high-intensity activities when making use of heart rates and standard graded maximal oxygen uptake test values. Lastly, the hypothesis that was set for the third purpose of the study was that significant differences will exist with regard to the absolute and relative total match time spent in each heart rate intensity zone during u/15 high school rugby games when making use of heart rates and standard graded maximal oxygen uptake test values.

A cross-sectional experimental study design was used to test the hypothesis of this study. Information was obtained by means of a questionnaire and a test battery. In this study twenty-four u/15 rugby players were monitored over the course of one season to determine the intensities of several rugby union matches. A standard incremental running test to the point of exhaustion was completed by each of the players in the period between rugby games. Each of the players' heart rate intensity zones were individually determined by making use of this test. Players' heart rate values were then recorded during several rugby games which were played on rugby grounds in the Potchefstroom area. The heart rates were then categorised according to the different heart rate intensity zones that were determined so that the researchers could analyse the time spent in each of the intensity zones.

Subjects

The subjects were twenty-four u/15 rugby union players from the 1st and 2nd teams of a high school in the Potchefstroom area of the North-West Province in South Africa. The characteristics of the mentioned subjects are presented in Table 1. The school was selected due to its history of excelling in rugby union as well as the team's previous season's accomplishments (they won the prestigious provincial league as u/14 players). The criteria for including the players' data in the study were as follows: they had to spend at least 80% of the game on the field; they had to complete a graded maximal running test within seven days of the rugby match; they must not have experienced any health or injury-related problems at the time of testing; and they must have formed part of the u/15 first or second rugby union teams of the high school which was targeted for this study. All players not adhering to these criteria were excluded from the study. Twenty-four players' (12 from each team) heart rates were monitored for the duration of several home games during the 2012 season. The data was collected during the in-season period that spanned from April to June. The objectives and procedures of the study were explained in writing to the players and their parents and informed consent forms (as prescribed by the researcher's university) were completed by the parents/guardians of the players and all the players. The study protocol was approved by the Ethics Committee of the North-West University.

TABLE 1. Physical characteristics of subjects*

Parameters	Subjects (*n* = 24)	Range
Age (y)	14.86 ± 0.35	14.10-15.30
Body stature (cm)	176.7 ± 5.69	166.40-189.40
Body mass (kg)	74.6 ± 13.94	56.20-111.90

*Values are mean±*SD*.

Procedures

The subjects reported at the laboratory after school where they completed a demographic and general informational questionnaire. The subjects' exercise habits, injury occurrence and competing levels were also obtained by means of this questionnaire. After completion of the questionnaire, body stature was recorded to the nearest 0.1 cm by means of a stadiometer (Harpenden portable stadiometer, Holtain Limited, UK.) and body mass was recorded to the nearest 0.1 kg with a portable electronic scale (BFW 300 Platform scale, Adam Equipment Co. Ltd., UK.). After the anthropometric measurements were taken, each player was subjected to a standard graded maximal oxygen uptake test.

Standard graded maximal oxygen uptake test: The standard graded maximal oxygen uptake ($\dot{V}O_{2max}$) test was conducted by means of open-circuit spirometry. Each subject performed the incremental test to the point of exhaustion on a Woodway Pro XL Treadmill (Woodway, W229 N591, Foster Ct, Waukesha, WI). Before commencement of the test, the players warmed up by running on the treadmill for 5 min at 8·km·h^{-1} and for 30 s at 15·km·h^{-1}. This was followed by the execution of static and dynamic stretches for the shoulders, arms, chest, abdomen, upper and lower back as well as the upper and lower legs. At commencement of the incremental test the first 2 min were performed at 8 km·h^{-1}, after which the treadmill speed was increased to 10·km·h^{-1} and thereafter by 1 km·h^{-1} every minute. Expired air was continuously sampled by an Oxycon Pro static ergo spirometry 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 stopped if the player indicated that total exhaustion had been reached or if the criteria for reaching the $\dot{V}O_{2max}$ value were achieved (e.g. a respiratory exchange ratio-value higher that 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) (7,17). Throughout the test, heart rate was recorded for each 5 s period by means of a Fix Polar Heart Rate Transmitter Belt (Polar Electro OY, Kempele, Finland). A cool-down period followed after conclusion of the incremental test and consisted of running on the treadmill at 10 km·h^{-1} until the heart rate had stabilised on 120 bpm.

Ventilatory threshold point (VTP) and respiratory compensation point (RCP): The results of the graded test were used to determine the ventilatory threshold (VT) 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 $\dot{V}_E$ (4). The RCP was taken as the point which corresponded to an increase in both $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$ (4). VTP and RCP were visually detected by two independent experienced researchers. The different gas exchange phases were used to determine the heart rates that corresponded to the three exercise intensities (4). Heart rates that corresponded to the exercise intensities below VT were classified as low intensity heart rates; heart rates that corresponded to the exercise intensities between VT and RCP were classified as moderate intensity heart rates and heart rates that correspond to the exercise intensities above RCP were classified as high intensity heart rates (23).

Rugby match heart rates: The heart rate data were collected via the measurement of the players' match play heart rates during several matches in the 2012 season. The players' heart rates were measured with the use of a Polar Team² Pro Electro system (Kempele, Finland) and recorded on a laptop computer with the Polar Team² Pro software program. A Polar electrode belt was strapped around the chest at the lower sternum of each player during the warm-up period before each match.

Statistical Analyses

The Statistical Data Processing Package (25) 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 each of the graded test results obtained during the periods before the games took place. The time spent in the different intensity zones (1, 2 and 3) was then expressed as a percentage of the total match time (excluding the warm up time before the matches and the half-time period). Secondly, the descriptive statistics (averages, minimum, maximum and standard deviation values) were calculated for each variable. Thirdly, a dependent t-test was used to determine the significance of differences with regard to the time periods and percentage of time each player spent in the three heart rate intensity zones. The level of significance was set at $p \leq 0.05$.

RESULTS

Standard graded maximal oxygen uptake test

The results of the standard graded maximal oxygen uptake test are presented in Table 2. The players obtained an average $\dot{V}O_{2max}$ value of 49.20 ml·kg^{-1}·min^{-1} at an average HR value of 196.94 bpm during the standard graded maximal oxygen uptake test. The VT occurred at 154.33 bpm, which was calculated to be 77.68% of HR_{max}. A further analysis also revealed that the average $\dot{V}O_2$ reached at the VT was 31.08 ml·kg^{-1}·min^{-1}, which is 63.5% of the $\dot{V}O_{2max}$. The RCP occurred at 87.38% of $\dot{V}O_{2max}$ (42.80 ml·kg^{-1}·min^{-1}) and at an average heart rate of 184.4 bpm, which was determined to be 92.72% of the HR_{max}. The HR for the three intensity zones were determined to be: <154.33 bpm (low intensity zone), 154.33-184.35 bpm (moderate intensity zone) and >184.35 bpm for the high intensity zone.

Rugby union match heart rate analysis

All the descriptive statistics for the measurements obtained from the match analysis are presented in Table 3. The adolescent players reached an average HR_{max} of 199.9 bpm but obtained an average heart rate of 169.9 bpm which corresponds to 85% of their HR_{max} during each of the matches. This average heart rate falls within the moderate intensity zone when categorized according to the heart rate intensity zones, which are presented in Table 2. The average time the players spent on the field was 47 min and 11 s out of the total possible game time of 51 min and 8 s.

TABLE 2. Standard graded maximal oxygen uptake test measurements of subjects*

Parameters	Subjects (*n = 24)*	Range
$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	49.24 ± 6.62	35.85 - 61.30
$\dot{V}O_{2max}$ HR (bpm)	196.94 ± 7.81	184.00 - 211.50
HR_{max} (bpm)	197.02 ± 7.48	184.50 - 211.00
RER_{max}	1.21 ± 0.06	1.09 - 1.28
VT (%$\dot{V}O_{2max}$)	63.47 ± 6.88	48.30 - 770.0
VT (ml·kg^{-1}·min^{-1})	31.08 ± 4.35	22.78 -40.28
VT (RER)	0.89 ± 0.07	0.77 - 1.08
VT (bpm)	154.33 ± 9.57	144.00 - 186.00
VT (% HR_{max})	77.67 ± 5.14	70.96 - 90.29
RCP (%$\dot{V}O_{2max}$)	87.38 ± 9.69	49.29 - 97.80
RCP (ml·kg^{-1}·min^{-1})	42.80 ± 6.31	26.52 - 53.42
RCP (RER)	1.04 ± 0.05	0.96 - 1.13
RCP (bpm)	184.40 ± 8.66	171.00 - 202.00
RCP (% HR_{max})	92.72 ± 4.10	87.47 - 98.67
Low-intensity HR zone (bpm)	<154.33 ± 9.57	<144.00 - 186.00
[% HR_{max}]	[≤77.68 ± 5.14]	[<70.96 - 90.30]
Moderate-intensity HR zone (bpm)	154.33 - 184.40	144.00 - 202.00
[% HR_{max}]	[77.68 - 92.72]	[70.96 - 92.72]
High-intensity HR zone (bpm)	>184.40 ± 8.66	>171.00 - 202.00
[% HR_{max}]	[>92.72 ± 4.10]	[>84.47 - 98.67]

*Values are mean±*SD*. $\dot{V}O_{2max}$ - 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; VT (ml·kg^{-1}·min^{-1}) - oxygen uptake at the ventilatory threshold; VT (km·h^{-1}) - treadmill speed at ventilatory threshold; VT (RER) - respiratory exchange ratio at ventilatory threshold; VT1 (bpm) - heart rate at the ventilatory threshold; VT (% 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 measurements*

Variable	Mean	Range
HR_{max} (bpm)	199.9 ± 8.17	186.0 - 217.0
HR_{avg} (bpm)	169.9 ± 8.7	148.5 - 185.9
Game time (min:s)	47:11 ± 3:46	37:42 - 51:08

*Values are mean±*SD*.
HR_{max} - maximum heart rate; HR_{avg} - average heart rate.

The results with regard to the match intensity analysis which was performed by making use of the different heart rate zones are presented in Table 4. From the results in Table 4 it is clear that players spent the majority of match time in the moderate intensity heart rate zone with an average of 27 min and 49 s that corresponds to 56.34% of the total match spent in this zone. The second most time was spent in the HIZ (23.03% of total match time) with 10 min and 55 s of the total match duration. Only 9 min and 6 s of the total match were spent in the LIZ, which relates to 19.95% of the total match time spent in this zone. However, the average duration of low intensity bouts was higher (67 s) than the low (40 s) and high (39 s) intensity bouts, respectively. Significant differences were observed for all the above-mentioned values between the low and moderate intensity as well as between moderate and high intensity zones.

TABLE 4. Descriptive statistics and significance differences between the measurements related to the match intensity analyses*

Variables	LIZ	MIZ	HIZ
Total time spent in each zone during the matches (min:s)	9:06 ± 7:37[a]	27:49 ± 9:15[ab]	10:55 ± 7:22[b]
Relative total time spent in each zone during the matches (%)	19.95 ± 16.73[a]	56.34 ± 18.7[ab]	23.03 ± 16.27[b]
Duration of different intensity bouts during the matches (min:s)	00:40 ± 00:33[a]	01:07 ± 00:33[ab]	00:39 ± 00:17[b]

*Values are mean±*SD*

LIZ - Low intensity heart rate zone; MIZ – Moderate intensity heart rate zone; HIZ – High intensity heart rate zone

When the same letter appears next to the values of two intensity zones, a significant difference ($p < 0.05$) is present

DISCUSSION

No research exists that has made use of the heart rate and standard graded maximal oxygen uptake test values to classify the different exercise intensity heart rates and to determine the game intensities of adolescent rugby union games. Hence the purposes of this study was firstly to determine the heart rate and standard graded maximal oxygen uptake test values of u/15 high school rugby players; secondly, to determine the intensities of u/15 high school rugby union games when making use of heart rates and standard graded maximal oxygen uptake test values; and lastly, to determine whether the absolute and relative total match time spent in each heart rate intensity zone during u/15 high school rugby games are significantly different when making use of heart rates and standard graded maximal oxygen uptake test values. The study succeeded in firstly showing that adolescent rugby players obtained an average $\dot{V}O_{2max}$ value of 49.24 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ at an average $\dot{V}O_{2max}$ HR value of 196.94 bpm; a VT of 77.68% of the HR_{max} (154.33 bpm) that was reached at a $\dot{V}O_2$ of 31.08 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$; a RCP at 87.38% of $\dot{V}O_{2max}$ (42.80 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$) at an average heart rate of 184.40 bpm, which was determined to be 92.72% of the HR_{max} during a standard graded maximal oxygen uptake test. The HR for the three intensity zones were determined to be: <154.33 bpm (low intensity zone), 154.33-184.35 bpm (moderate intensity zone) and >184.35 bpm for the high intensity zone. By using the last-mentioned heart rate zones, the researchers revealed that the adolescent players spent the majority of match time in the moderate intensity heart rate zone (27 min and 49 s, 56.34% of the total match time), followed by the high intensity zone (10 min and 55 s, 23.03% of the total match time) and the low intensity zone (9 min and 6 s, 19.95% of the total match time). However, the average duration of low intensity bouts was higher (67 s) than the low (40 s) and high (39 s) intensity bouts, respectively. Lastly, significant differences were observed for all the above-mentioned values between the low and moderate intensity as well as between the moderate and high intensity zones.

Therefore in view of the above-mentioned research findings, the first hypothesis of the study which stated that u/15 high school rugby union games will be characterised by more low and moderate-intensity activities than high-intensity activities when making use of heart rates and standard graded maximal oxygen uptake test values, can be partly accepted. The rugby games were characterised by more moderate than high intensity activities, but more time was spent in the high intensity than the low intensity heart rate zone. The second hypothesis, which stated that significant differences will exist with regard to the absolute and relative total match time spent in each heart rate intensity zone during u/15 high school rugby games when making use of heart rates and standard graded maximal oxygen uptake test values, can also only be partly accepted. Significant differences were only observed for the last-mentioned values between the low and moderate intensity as well as between the moderate and high intensity zones. However, no significant differences were found between the absolute and relative total match time spent in the low and high intensity zones.

It is difficult to draw comparisons between the findings of this study and those of similar studies due to the fact that no other studies had made use of the heart rate and standard graded maximal oxygen uptake test values to classify the different exercise intensity heart rates and to determine the game intensities of high school rugby union games. As been mentioned before, only three groups of researchers could be found that have investigated the match characteristics of adolescent rugby union players (u/19 players and younger). However, all three of these researcher groups used GPS technology to do the match analysis and only one of the researcher groups used u/16 players as their subject group (13). It will therefore be more applicable to compare the findings of Hartwig et al. (13) to the results of this study. Hartwig et al. (13) gave no indication of the time periods spent on activities in the two intensity zones, the average duration of activity bouts in each of the intensity zones or of the percentages of maximum heart rates relevant for determining each of the intensity zones. Therefore it was not possible to compare the last-mentioned results between this and previous studies of adolescent rugby players. According to Hartwig et al. (13) 94.8% of the match time was spent on low intensity activities such as standing still, walking and jogging, whereas 19.95% of the total match time was spent in the low intensity zone in this study. Furthermore, Hartwig et al. (13) found the percentage of time spent in high intensity activities such as striding, sprinting and static exertion type of activities to be 4.5% for u/16 players compared to 23.03% of the total match time spent in the high intensity zone in this study by the u/15 players. It is not possible to compare the results with regard to the moderate intensity zone of this study to those of previous studies due to the fact that previous studies only categorised activities into high and low intensity activities, with no moderate intensity activities being specified.

The difference in categorization between this and previous studies may serve as a possible reason for the differences in the distribution of intensity zones. Furthermore, the use of GPS technology to measure and describe the physical demands placed on players during a match may not reflect the direct individual physiological response of each player to the execution of different activities. In GPS analyses the intensities of different activities are defined by the types of movement and the speed of these movements, although players' individual heart responses may differ for similar activities. Also, in GPS analyses the periods each player spent in the different intensity zones are determined by the time period of each movement, whereas the intensity zone periods in heart rate and standard graded maximal oxygen uptake test analyses-related studies are determined by the heart rate itself, which will probably take a few seconds to decrease to a lower intensity zone level.

Significant differences ($p \leq 0.05$) were observed for all the match intensity-related measurements between the low and moderate intensity as well as between the moderate and high intensity zones. These results accentuate the huge amount of time and percentage of total match time as well as the long duration of activity bouts that were performed in the moderate intensity zone compared to all the other intensity zones during junior rugby match play. These results would suggest that adolescent rugby players will depend more on the aerobic energy system for energy delivery during a rugby match due to the fact that they spend most of match time on activities which produce heart rates that corresponded to the exercise intensities between VT and RCP. However, the intermittent nature of a rugby game forces players to frequently repeat high intensity bouts (39 s at a time in the high intensity zone) interrupted by periods of short rest (40 s at a time in the low intensity zone), which also places a rather high demand on the anaerobic energy systems. Usually, the high intensity activities will utilise the short-term ATP/CP energy system, but due to the longer duration of these activities (>8-10 s) as well as the short rest periods between the high intensity bouts (40 s at a time) that do not allow the body to fully resynthesize the ATP/CP stores (3- 5 min), a rather high demand may be placed on the anaerobic lactic energy system (16,17).

Although the one available study that has investigated the use of heart rate and standard graded maximal oxygen uptake test values for determining the match demands of rugby union players focussed on university-level players (23), it would probably be of use to compare the results of this study with these of ours. Comparisons revealed that the adolescent rugby players in this study spent much more time in the moderate intensity heart rate zone (56.34% *versus* 33.6%), more or less similar time in the low intensity heart rate zone (19.95% *versus* 22.6%) and much less time in the high intensity zone (23.03% *versus* 43.7%) than the university-level players. However, the average duration for low and moderate intensity bouts was much higher (67 s *versus* 29 s; 40 s *versus* 29 s), whereas the average duration for high intensity bouts was much lower (39 s *versus* 77 s) for the adolescent players than for the university-level players. These differences in the match intensity-related characteristics suggest that the demands placed on adolescent and senior players during match play differ considerably, with the demands of senior rugby being much higher than adolescent match play. Rule differences which dictate a shorter total match length for junior rugby and a shorter duration of and less taxing scrums for adolescents (17) may serve as an explanation for these differences.

To conclude, the research in this study seems to suggest that the intensities of u/15 high school rugby union games can be determined by making use of heart rates and standard graded maximal oxygen uptake test values. This is an important finding due to the limitations that have been identified with regard to the use of time-motion, blood lactate, heart rate and GPS analyses to determine the characteristics and demands of rugby union matches. It also stresses the need for more rugby union match analysis studies on junior rugby players which make use of the last-mentioned method in order to determine the energy requirements and match demands of this group of players more accurately.

Although the results of this study are very relevant for providing important information to the rugby fraternity in general, it must be underscored that the adolescent players that were targeted in this study were players from one school, in one province of South Africa which means that the results cannot be generalized to all adolescent rugby players. Furthermore, several authors have shown significant differences between laboratory and field-base performances (22), which may suggest that the standard graded treadmill test may not be the most specific test for determining the heart rate-intensity zones for use in categorising rugby union game intensities. In this regard, a field test such as the Yo-Yo intermittent recovery (IR) test (2) which is performed while wearing a portable gas analyser apparatus, may serve as a more sport-specific test to measure the direct $\dot{V}O_2$ and the two physiological gas exchange points of rugby players.

PRACTICAL APPLICATIONS

An understanding of the specific demands of rugby union will enable coaches, sport scientists and other sport-related professionals to plan and implement the most effective training programs and testing procedures for adolescent rugby players. However, a variety of physiological responses are elicited by rugby due to the repeated high-intensity sprints and frequent contact situations players face during a game, which make rugby exceptionally complex to analyse compared to individual sports. From the above-mentioned discussion it is clear that the match analysing methods, such as time motion analysis, GPS analysis, HR and blood lactate measuring methods that have thus far been used, have various drawbacks, which make it inaccurate for use in determining the match demands of rugby union. Therefore the use of heart rates and standard graded maximal oxygen uptake test values may provide a more accurate method for analysing the demand of adolescent rugby union matches. The results of this new analysing method seem to suggest that adolescent rugby union coaches and sport scientists need to focus more on moderate intensity activities that tax the aerobic energy systems for periods of 67 s at a time at a heart rate of more or less 78 to 93% of HR_{max} during training sessions. Furthermore, it shows that adolescent players' anaerobic energy system also needs to be taxed during training session by using activities with a duration of more or less 39 s at a time at a heart rate of above 93% of HR_{max}.

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CHAPTER: 4

4 Heart Rate And Graded Maximal Test Values To Determine Positional Rugby Union Game Intensities Of Adolescent Boys

TITLE: HEART RATE AND GRADED MAXIMAL TEST VALUES TO DETERMINE POSITIONAL RUGBY UNION GAME INTENSITIES OF ADOLESCENT BOYS

RUNNING HEAD: THE DETERMINATION OF POSITIONAL RUGBY UNION GAME INTENSITIES

LABORATORY: INSTITUTE FOR SPORT SCIENCE AND DEVELOPMENT, FNB NWU HIGH PERFORMANCE INSTITUTE OF SPORT, NORTH-WEST UNIVERSITY, POTCHEFSTROOM CAMPUS, POTCHEFSTROOM, SOUTH AFRICA

AUTHORS: FRANCOIS WILLEMSE & BEN COETZEE

DEPARTMENT: PHYSICAL ACTIVITY, SPORT AND RECREATION FOCUS AREA, FACULTY OF HEALTH SCIENCES, NORTH-WEST UNIVERSITY, POTCHEFSTROOM CAMPUS, POTCHEFSTROOM, SOUTH AFRICA

CORRESPONDING AUTHOR:
FRANCOIS WILLEMSE
SCHOOL OF EDUCATION
INTERNAL BOX 539
FACULTY OF EDUCATION,
NORTH-WEST UNIVERSITY
POTCHEFSTROOM CAMPUS
POTCHEFSTROOM
2520
SOUTH AFRICA

TEL: +27 18 299 1914
FAX: +27 18 299 1716
EMAIL: 10961542@nwu.ac.za

ABSTRACT

The purposes of the present study were firstly, to determine the significant positional differences in the heart rate (HR) and standard incremental maximal oxygen uptake test values of u/15 high school rugby players and secondly, to determine the significant positional differences in the intensities of u/15 high school rugby union matches when making use of heart rates and standard incremental maximal oxygen uptake test values. The 24 school boys' heart rates were categorized in three zones, namely: (1) low intensity zone or LIZ (below ventilatory threshold (VT)), (2) moderate intensity zone or MIZ (between VT and respiratory compensation point (RCP)) and (3) high-intensity zone or HIZ (above RCP). These zones were determined with a graded maximal test in a controlled laboratory environment. The standard incremental test-related measurements revealed that average HR at the VT was significantly higher for the backs than for the forwards, whereas the average $\dot{V}O_2$ at RCP was significantly higher for the forwards than for the backs. Furthermore, the forwards displayed significantly lower heart rates for the LIZ and MIZ than the backs. The match analysis results revealed that the forwards obtained significantly lower values for the total time and relative total time spent in the LIZ than the backs. No other significant differences were observed between the two positional groups. To conclude, the research in this study seems to suggest that the position-specific intensities of u/15 high school rugby union matches can be determined and compared by making use of these players' heart rates and standard graded maximal oxygen uptake test values.

KEY WORDS: rugby union, match play intensities, $\dot{V}O_{2max}$, forwards, backs

INTRODUCTION

Rugby union teams are composed of fifteen players of which eight players are classified as forwards (numbers 1-8) and seven players as backs (numbers 9-15)(8). The forwards' main function is to compete for and gain possession of the ball while the backs must use the ball to advance down the field or to score points, whereas both player groups should be able to defend effectively (1). Match analysis is an applicable method for quantifying the on-field movements and activities of individuals (1) and can therefore be used to determine the positional differences in rugby union match play demands. This obviously also applies to junior rugby union due to a need to better understand the match demands of adolescent players in order to assist coaches and other sport-related professionals to create more match-specific training activities and programmes (11). Despite this need, the positional demands of adolescent rugby union players are poorly documented, and there are no evidence-based strategies to monitor participation loads (11).

Only two studies on u/19 (5,24) and one study on u/16 rugby union players (12) in which the match characteristic differences between the two positional groups (forwards and backs) were described by means of global positioning system (GPS) technology could be found. Results with regard to the total percentage of match time spent standing still between the forwards of the two age groups delivered more or less similar results for the study of Deutsch et al. (6) (u/19 = 45.9% versus u/16 = 44.5%), whereas Venter et al. (24) reported a lower value of 22.4%. The study results of Deutsch et al. (6) obtained a higher value for the backs in the percentage of time spent standing still (40.8%) than those of Hartwig et al. (12) (32.7%) and Venter et al. (24) (20.8%). However, similar values were found for the total percentage of match time spent walking by the forwards in the studies of both Deutsch et al. (6) and Hartwig et al. (12) (15.4%) whilst Venter et al. (24) reported a much higher value of 44.5%. With regard to the backs' percentage of time spent walking, both Venter et al. (24) (56.6%) and Hartwig et al. (12) (48.4%) obtained much higher values than those of Deutsch et al. (6) (27.3%). Position-specific values for the percentage of match time spent jogging varied between 14.5% and 13.6% (12), 20.6% and 18.7% (5) as well as 24.8% and 17.8% (24) for the forwards and backs respectively. The values for the total percentage of match time spent on striding differed from one group of researchers to the next for the two positional groups with Deutsch et al. (6) reporting values of 1.85% and 2.7%, Hartwig et al. (12) reporting values of 3.6% and 3.1%, and Venter et al. (24) reporting values of 7.8% and 4.5% for the forwards and backs respectively. Hartwig et al. (12) found slightly higher values for the percentage of total match time spent sprinting (forwards: 0.9%; backs: 1.3%) than did Deutsch et al. (6) (forwards: 0.4%; backs: 1.05%) and Venter et al. (24) (forwards: 0.4% and backs: 0.9%). Venter et al. (24) was the only group of researchers that reported on the time spent on maximal sprinting during a match with an average value of 0.06% for both forwards and backs, whereas only Deutsch et al. (6) reported on the average percentage of total match time spent on static exertion type of activities with average values of 13.9% and 1.3% for the forwards and backs respectively.

The position-specific results for adolescent players seem to suggest that forwards spent between 74.4% and 91.7% on low-intensity activities (standing still, walking and jogging) during a rugby match compared to the backs that spent considerably more time on these type of activities (between 86.8% and 95.6%) (5,12,24). In contrast, a comparison of the percentage of time spent on high-intensity activities (striding, sprinting and static exertion type of activities) between the two positional groups showed that the forwards obtained much higher values (8.3% - 16.55%) than the backs (4.4% - 10.5%) (6,12,24).

Although these results do allow researchers and other sport-related professionals to determine the characteristics and demands of junior rugby union matches, the use of GPS analyses in the last-mentioned studies have been questioned due to certain limitations that have been identified. Like automated tracking devises, GPS systems are costly and there are no low-cost GPS units available, nor software, designed for use in team sports (19). Despite the fact that GPS devices have been shown to be reliable and valid for measuring total distances during longer-duration activities, research showed that GPS devices cannot be used to measure brief, high-intensity sprints, or slow and fast accelerations over distances of less than 20 m, regardless of sampling rate (15). Coutts and Duffield (4) supported this finding by concluding that although the accuracy and reliability level of GPS devices are acceptable for total distance and peak speeds during high-intensity, intermittent exercise, it may not provide reliable measures for higher-intensity activities. A study of Barbero-Álvarez et al. (2) found that GPS devices are sensitive enough to detect relatively small changes in serial measurements of repeated sprint performance when completed over distances of more than 30 m – which still leaves us with a problem regarding repeated sprinting bouts of much shorter distances which are most commonly found in rugby union (average duration between 1.4 and 2.5 s). Furthermore, Gray and Jenkins (10) pointed out that the accuracy and reliability of distance and velocity derived from GPS data still need to be determined for highly specific match-related activities.

These limitations have compelled researchers to also investigate the use of a combination of methods in order to increase the accuracy and validity of match analysis results. A more accurate way of measuring exercise intensities during the execution of different movement patterns or activities is to determine the heart rates at two definite gas exchange points, namely ventilatory threshold (VT) and respiratory compensation point (RCP) for each individual by means of a cardio respiratory exercise test (20). By determining the VT and RCP, three exercise-intensity zones (low, medium and high-intensity zones) can be identified (2,18) and the percentage of time the players spend in each intensity zone during a match can be determined. In spite of the benefits that can be derived from the use of this technique, only one researcher made an attempt to use this technique for determining the match intensities of university-level rugby union players (20). Although this study also showed that forwards spent significantly more time in the high-intensity heart rate zone than the backs during a match, the percentage of time both positional groups spent in this zone was considerably higher than previously reported values of time motion and GPS analyses-related studies (21). These differences may be attributed to the use of heart rates instead of movement speeds to determine the intensities of activities (20). Each player's heart rate-intensity zones were also individually determined through the cardio respiratory exercise test, which provided a more accurate reflection of the physical demands placed on each player during match play, than time motion and GPS analysis studies (20).

Therefore, in light of the above-mentioned research findings which suggest that the demands of junior rugby union matches need to be quantified by making use of a combination of methods instead of GPS analyses alone and that a scarcity exists with regard to the number of publications that have focussed on the positional differences between the match demands of young rugby players, the purposes of the present study were firstly, to determine the significant positional differences in the heart rate and standard incremental maximal oxygen uptake test values of u/15 high school rugby players and secondly, to determine the significant positional differences in the intensities of u/15 high school rugby union matches when making use of heart rates and standard incremental maximal oxygen uptake test values. Results of this study could possibly enable future coaches, rugby players and sport scientists of u/15 high school rugby teams to compile position-specific conditioning programs that will enable players to reach their full potential when participating in rugby matches.

METHODS

Experimental Approach to the Problem

Due to the fact that no research exists that has made an attempt to determine the positional differences in the heart rate and standard incremental maximal oxygen uptake test values of u/15 high school rugby players, no hypothesis was set for the first purpose of the study. For the second purpose of the study the specific hypothesis under scrutiny was that the u/15 forwards will obtain significantly higher values for the amount and percentage of time spent in the high-intensity heart rate zone than the backs, whereas the u/15 backs will obtain significantly higher values for the amount and percentage of time spent in the low-intensity heart rate zone than the forwards during high school rugby union matches when making use of heart rates and standard incremental maximal oxygen uptake test values. A cross-sectional experimental study design was used to test the hypotheses of this study. Information was obtained by means of a questionnaire and a test battery. In this study twenty-four u/15 rugby players were monitored over the course of one season to determine the intensities of several rugby union matches. A standard incremental running test to the point of exhaustion was completed by each of the players in the period between rugby matches. Each of the players' heart rate-intensity zones were individually determined by making use of this test. Players' heart rate values were then recorded during several rugby matches, which were played on rugby grounds in the Potchefstroom area. The heart rates were then categorised according to the different heart rate-intensity zones that were determined so that the researchers could analyse the time spent in each of the intensity zones.

Subjects

The subjects were twenty-four u/15 rugby union players from the 1st and 2nd teams of a high school in the Potchefstroom area of the North-West Province in South Africa. The school was selected due to its history of excelling in rugby union as well as the team's previous season's accomplishments (they won the prestigious provincial league as 14 year old players). The players were divided into two positional groups for each of the matches, namely forwards (n = 15) and backs (n = 9). The forwards consisted of the eight front-line players and the backs consisted of the seven back-line players. The characteristics of the mentioned subjects are presented in Table 1. The criteria for including the players' data in the study were as follow: they had to spend at least 80% of the match on the field; they had to complete a graded maximal running test within seven days of the rugby match; they must not have experienced any health or injury-related problems at the time of testing; and they must have formed part of the u/15 first or second rugby union teams of the high school which was targeted for this study. All players not adhering to these criteria were excluded from the study. Twenty-four players' (12 from each team) heart rates were monitored for the duration of several home matches during the 2012 season. The data was collected during the in-season period that spanned from April to June. The objectives and procedures of the study were explained in writing to the players and their parents and informed consent forms (as prescribed by the researchers' institution) were completed by the parents/guardians of the players and all players. The study protocol was approved by the Ethics Committee of the North-West University.

TABLE 1. Physical characteristics of subjects*

Parameters	Total group (n = 24)	Forwards (n = 15)	Backs (n = 9)
Age (y)	14.86 ± 0.35	14.85 ± 0.39	14.89 ± 0.29
Body stature (cm)	176.7 ± 5.69	177.79 ± 5.77	175.96 ± 5.80
Body mass (kg)	74.6 ± 13.94	79.21 ± 14.69	66.95 ± 8.70*

Values presented as mean ± *SD*

*$p \leq 0.05$

Testing Procedures

The subjects reported at the laboratory after school where they completed a demographic and general informational questionnaire. The subjects' exercise habits, injury occurrence and competing levels were also obtained by means of this questionnaire. After completion of the questionnaire, body stature was recorded to the nearest 0.1 centimetre by means of a stadiometer (Harpenden portable stadiometer, Holtain Limited, UK.) and body mass was recorded to the nearest 0.1 kg with a portable electronic scale (BFW 300 Platform scale, Adam Equipment Co. Ltd., UK.). After the anthropometric measurements had been taken, each player was subjected to a standard incremental maximal oxygen uptake test.

Standard incremental maximal oxygen uptake test: The standard incremental maximal oxygen uptake ($\dot{V}O_{2max}$) test was conducted by means of open-circuit spirometry. Each subject performed the incremental test to the point of exhaustion on a Woodway Pro XL Treadmill (Woodway, W229 N591, Foster Ct, Waukesha, WI). Before commencement of the test, the players warmed up by running on the treadmill for 5 min at 8 km·h^{-1} and for 30 s at 15·km·h^{-1}. This was followed by the execution of static and dynamic stretches for the shoulders, arms, chest, abdomen, upper and lower back as well as the upper and lower legs. At commencement of the incremental test the first 2 min were performed at 8 km·h^{-1} after which the treadmill speed was increased to 10 km·h^{-1} and thereafter by 1 km·h^{-1} every minute. Expired air was continuously sampled by an Oxycon Pro static ergo spirometry 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 total exhaustion had been reached or if the criteria for reaching the $\dot{V}O_{2max}$ value were achieved (e.g. a respiratory exchange ratio-value higher that 1.15 at test termination; oxygen consumption ceases to rise and reaches a plateau or begins to fall even though the work rate continued to increase or the maximal age-specific heart rate was reached) (5,16). Throughout the test, heart rate was recorded for each 5 s period by means of a Fix Polar Heart Rate Transmitter Belt (Polar Electro OY, Kempele, Finland). A cool-down period followed after conclusion of the incremental test and consisted of running on the treadmill at 10 km·h^{-1} until the heart rate stabilised on 120 bpm.

Ventilatory threshold point (VT) and respiratory compensation point (RCP): The results of the incremental test were used to determine the ventilatory threshold (VT) 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 $\dot{V}_E$ (3). The RCP was taken as the point which corresponded to an increase in both $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$ (3). VTP and RCP were visually detected by two independent experienced researchers. The different gas exchange phases were used to determine the heart rates that corresponded to the three exercise intensities (3). Heart rates that corresponded to the exercise intensities below VT were classified as low-intensity heart rates; heart rates that corresponded to the exercise intensities between VT and RCP were classified as moderate-intensity heart rates and heart rates that correspond to the exercise intensities above RCP were classified as high-intensity heart rates.

Rugby match heart rates: The heart rate data were collected via the measurement of the players' match play heart rates during several matches in the 2012 season. The players' heart rates were measured with the use of a Polar Team² Pro Electro system (Polar Electro, Kempele, Finland) and recorded on a laptop computer with the Polar Team² Pro software program. A Polar electrode belt was strapped around the chest at the lower sternum of each player during the warm–up period before each match.

Statistical Analysis

The Statistical Data Processing Package (22) was used to process the collected data. Firstly, the heart rates each player attained during the matches were categorized into the three intensity zones (low, moderate and high) according to each of the incremental test results obtained during the periods before the matches took place. The time spent in the different intensity zones (1, 2 and 3) was then expressed as a percentage of the total match time (excluding the warm up time before the matches and the half-time period). Secondly, the descriptive statistics (averages, minimum, maximum and standard deviation values) were calculated for each variable and positional group. Thirdly, an independent test was used to determine whether any significant differences existed with regard to the different variables between the two positional groups. The level of significance was set at $p \leq 0.05$.

RESULTS

Standard incremental maximal oxygen uptake test

The results of the standard incremental maximal oxygen uptake test for the different positional groups are presented in Table 2.

TABLE 2. Standard incremental test-related measurements of the different positional groups of players*

Parameters	Total group (*n* = 24)	Forwards (*n* = 15)	Backs (*n* = 9)
$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	49.2 ± 6.6	47.6 ± 7.3	51.9 ± 4.4
$\dot{V}O_{2max}$ HR	196.94 ± 7.81	196.42 ± 7.98	197.82 ± 7.91
HR_{max} (bpm)	197.02 ± 7.48	195.83 ± 6.96	199.0 ± 8.31
VT (% $\dot{V}O_{2max}$)	63.5 ± 6.9	62.3 ± 7.08	65.5 ± 7.4
VT (ml·kg^{-1}·min^{-1})	31.08 ± 4.35	29.32 ± 3.59	34.00 ± 4.07
VT (RER)	0.89 ± 0.07	0.87 ± 0.05	0.92 ± 0.09
VT (bpm)	154.3 ± 9.57	151.39 ± 6.16	159.24 ± 12.38$^{\#}$
VT (% HR_{max})	77.67 ± 5.14	76.13 ± 4.63	80.25 ± 5.16
RCP (% $\dot{V}O_{2max}$)	87.38 ± 9.69	88.34 ± 11.55	85.77 ± 5.64
RCP (ml·kg^{-1}·min^{-1})	42.8 ± 6.31	41.72 ± 6.95	44.59 ± 4.93
RCP (RER)	1.04 ± 0.05	1.03 ± 0.05	1.05 ± 0.05
RCP (bpm)	184.4 ± 8.66	183.28 ± 7.63	186.28 ±10.36
RCP (% HR_{max})	92.72 ± 4.10	91.99 ± 3.85	93.94 ± 4.43
LIZ HR zone (bpm)	<154.33 ± 9.57	<151.39 ± 6.16	<159.24 ± 12.38$^{\#}$
(% HR_{max})	[<77.67 ± 5.14]	[<76.13 ± 4.63]	[<80.25 ± 5.16]
MIZ HR zone (bpm)	154.33 -184.40	151.39 - 183.28	159.24 - 186.28$^{\#}$
(% HR_{max})	[77.67 - 92.72]	[76.13 - 91.99]	[80.25 - 93.94]
HIZ HR zone (bpm)	>184.4 ± 8.66	>183.28 ± 7.63	>186.28 ± 10.36
(% HR_{max})	[>92.72 ± 4.10]	[>91.99 ± 3.85]	[>93.94 ± 4.43]

*Values are mean ± *SD*; $\dot{V}O_{2max}$ - maximum oxygen uptake; HRmax - maximum heart rate; VT (% $\dot{V}O_{2max}$) - ventilatory threshold expressed as a percentage of the maximum oxygen uptake; VT (ml·kg^{-1}·min^{-1}) - oxygen uptake at the ventilatory threshold; VT (RER) - respiratory exchange ratio at ventilatory threshold; VT (bpm) - heart rate at the ventilatory threshold; VT (% 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 (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; LIZ- low-intensity zone; MIZ- moderate-intensity zone; HIZ- high-intensity zone; $^{\#}$ = $p \leq 0.05$.

The standard incremental test-related measurements revealed that in general the backs obtained higher values in all the measurements than the forwards, except, for the percentage of $\dot{V}O_{2max}$, where the RCP occurred. However, average HR at the VT was significantly higher for the backs than for the forwards, whereas the average $\dot{V}O_2$ at RCP was significantly higher for the forwards than for the backs. Furthermore, the forwards also displayed significantly lower heart rates for the LIZ and MIZ than the backs. No other significant differences were observed for the standard incremental test-related measurements.

Rugby union match heart rate analysis

All the descriptive statistics for the measurements that were obtained from the match analysis are presented in Table 3.

TABLE 3. Descriptive statistics for all the match analyses-related variables for the different positional groups*

Variable	Total group (n = 24)	Forwards (n = 15)	Backs (n = 9)
HR_{max} (bpm)	199.88 ± 8.17	200.4 ± 8.92	199.02 ± 7.15
HR_{min}(bpm)	127.6 ± 11.78	130.5 ± 10.04	122.8 ± 13.41
HR_{avg} (bpm)	169.9 ± 8.70	172.3 ± 6.61	165.8 ± 10.55
Match time (min:sec)	47:11 ± 03:46	47:45 ± 03:46	46:45 ± 03:53

*Values are mean ± *SD*; HRmax - maximum heart rate; HRmin – minimum heart rate; HRavg - average heart rate.

Although the forwards obtained higher values for all the above-mentioned variables than the backs, no significant differences were found between the two positional groups.

The results of the positional groups' match-intensity analysis (divided into low, moderate and high-intensity zones) are presented in Table 4.

TABLE 4. Descriptive statistics and significant differences between the match-intensity measurements of the two positional groups*

Positional groups	LIZ	MIZ	HIZ
	Total time spent in each intensity zone (min:s)		
Forwards	05:22 ± 04:18	30:00 ± 09:30	12:26 ± 6:57
Backs	15:11 ± 07:28#	23:17 ± 07:17	07:02 ± 06:50
	Relative time spent in each intensity zone (%)		
Forwards	12.5 ± 11.4	60.3 ± 19.04	27.4 ± 16.5
Backs	26.4 ± 27.6#	57.5 ± 16.9	17.6 ± 17.5
	Duration of different intensity bouts (min:s)		
Forwards	00:33 ± 00:35	01:10 ± 00:39	00:39 ± 00:16
Backs	00:51 ± 00:27	01:00 ± 00:23	00:37 ± 00:18

*Values are mean ± *SD,* LIZ – Low-intensity heart rate zone; MIZ – Moderate-intensity heart rate zone; HIZ – High-intensity heart rate zone.
= $p \leq 0.05$

Results showed that the highest percentage of match time for both the forwards and the backs was spent in the MIZ (60.3% and 57.5% of total match time respectively). The backs spent the second most time in the LIZ (26.4% of total match time) while the forwards spent the second most time in the HIZ (27.4% of total match time). The backs spent the minority of time in the HIZ (17.6%) while the forwards spent the minority of time in the LIZ (12.5%). With both player groups the duration of bouts in the different intensity zones shows that the MIZ bouts were the longest (70 s) for the forwards and the backs (60 s) and the HIZ bouts the shortest (39 s for the forwards and 37 s for the backs). Despite the afore-mentioned differences between the positional groups, the only variables for which the forwards obtained significantly lower values than the backs were the total time and relative total time spent in the LIZ.

DISCUSSION

No research could be found that has made use of the heart rate and standard incremental maximal oxygen uptake test values of adolescent players to determine the positional differences in intensities of rugby union matches. In view of this the purposes of this study were firstly, to determine the significant positional differences in the heart rate and standard incremental maximal oxygen uptake test values of u/15 high school rugby players and secondly, to determine the significant positional differences in the intensities of u/15 high school rugby union matches when making use of heart rates and standard incremental maximal oxygen uptake test values. Overall the results showed that the backs obtained significantly higher average HR at the VT and significantly higher HR's for the LIZ and MIZ as well as significantly lower average $\dot{V}O_2$ at RCP than the forwards. With regard to the match analysis-related results, the forwards obtained significantly lower values for the total time and relative total time spent in the LIZ than the backs. In view of these results the hypothesis which stated that the u/15 forwards will obtain significantly higher values for the amount and percentage of time spent in the high-intensity heart rate zone than the backs and that the u/15 backs will obtain significantly higher values for the amount and percentage of time spent in the low-intensity heart rate zone than the forwards during high school rugby union matches when making use of heart rates and standard incremental maximal oxygen uptake test values, is only partially accepted.

The significantly higher average HR at the VT for the backs compared to the forwards, and the significantly higher average $\dot{V}O_2$ at RCP for the forwards compared to the backs, may be an indication of differences in economy rate between the two positional groups. In this regard the backs seem to be more economical at higher exercise intensities than the forwards that are more economical at lower intensities. These results are probably related to the fact that a significantly higher body mass was observed in the forwards than in the backs. At low exercise intensities the extra body weight will probably not have a large effect but at higher exercise intensities the extra body weight will be detrimental to the effective and economical execution of running movements.

Due to the fact that no other studies had made use of the heart rate and standard graded maximal oxygen uptake test values to classify the different exercise-intensity heart rates and to determine the match-intensity positional differences of high school rugby union games, it is difficult to draw comparisons between the findings of this study and those of similar studies. The one group of researchers that did investigate the positional match analysis results of u/16 rugby union players made use of GPS analyses (12), and concluded that 94.5% and 95.1% of the match time was spent on low-intensity activities (such as standing still, walking and jogging) by the forwards and backs respectively. These values are much higher than the reported values for the percentage of match time spent in the LIZ by the u/15 forwards (12.5%) and backs (26.4%) in this study. In contrast, a comparison of the percentage of time spent in high-intensity activities (striding, sprinting and static exertion type of activities) and the percentage of time spent in the HIZ in this study showed that both the u/16 positional groups obtained much lower values (forwards: 4.5%, backs: 4.4%) (12) than the u/15 players (forwards: 27.4%, backs: 17.6%). Due to the unavailability or research, no comparisons could be drawn with regard to the time periods spent on activities in the two intensity zones, the average duration of activity bouts in each of the intensity zones or the percentages of maximum heart rates relevant for determining each of the intensity zones between this and other studies of 15-16-year-old rugby union players.

From the above-mentioned discussion it is clear that the u/15 players in this study spent much less time in the LIZ and much more time in the HIZ than the time periods spent by u/16 players on low and high-intensity activities. The differences in results between this and other studies are probably related to the fact that different methods were applied to determine the match intensities. In GPS-analyses studies the physical demands placed on players during a match are determined by the type of movements and the speed of these movements, whereas heart rate and standard graded maximal oxygen uptake test analyses make use of heart rate-intensity zones for determining the physical demands placed on players. It is important to note that players' individual heart responses may differ for similar type of activities and that this factor is not considered when making use of GPS analyses. Furthermore, during GPS analyses, the periods that each player spent in the different intensity zones are determined by the time period of each movement, whereas the intensity zone periods in heart rate and standard graded maximal oxygen uptake test analyses-related studies are determined by the heart rate itself, which will probably take a few seconds to decrease to a lower-intensity zone level. Also, previous studies categorised activities into high and low-intensity activities, instead of the three intensity activity zones which may also cause differences between the percentage of time spent in each zone.

The one study that used the heart rate and standard graded maximal oxygen uptake test values to determine the positional differences in game intensities among a group of university-level players (21) showed that forwards spent a significantly lower percentage of match time in the low-intensity heart rate zone (11.3% *versus* 34.2%) than the backs. In contrast, the backs spent significantly less time in the high-intensity heart zone (32.7% *versus* 54.6%) than the forwards (21). More or less similar results were found in this study with regard to the percentage of match time spent in the low-intensity heart rate zone by the forwards (12.5%), whereas the backs obtained much lower values for the same intensity zone category (26.4%). However, the differences with regard to the last-mentioned variable between the two positional groups were also significant. Interestingly, the forwards in the study of Sparks (21) obtained a much lower value for the percentage of time spent in the MIZ (34.1% *versus* 60.3%) and a much higher value for the percentage of time spent in the HIZ (54.6% *versus* 27.4%) than the players in this study. Similarly, the comparisons between the backs in the two studies revealed that the backs in this study obtained much lower values for the percentage of time spent in the HIZ (17.6% *versus* 32.7%) and dissimilarly much lower values for the percentage of time spent in the MIZ (57.5% *versus* 66.9%) than the backs in the study of Sparks (21). A further comparison between the two studies also showed that the average duration of high-intensity bouts was much higher for the forwards in the study of Sparks (21) than for the forwards in this study (101 s *versus* 39 s). However, the average durations of bouts in the LIZ and MIZ were much lower than the durations of bouts in this study (17 s *versus* 33 s and 26 s *versus* 70 s). In contrast, the average duration of high-intensity bouts was more or less similar for the backs in both studies (38 s *versus* 37 s), whereas the average durations for the rest of the bouts (low and moderate) were much lower for the backs in the study of Sparks (21) than for the backs in this study (43 s *versus* 51 s and 60 s *versus* 33 s).

Overall, the results in this study would suggest that the physical demands of backline play are less than the demands of frontline play during matches. The forwards are normally more involved in static exertion type of activities such as rucks, mauls and scrums (6,7,9,17). This notion is substantiated in this study by the 9.8% higher average percentage of total match time and time that the adolescent forwards spent in the HIZ compared to the backs (12 min 26 s *versus* 07 min 02 s) as well as the significant difference in the total time and relative total time spent in the LIZ between the two positional groups (forwards: 05 min 22 s; backs: 15 min 11 s and forwards: 12.5%; backs: 26.4%). According to Duthie et al. (9), the backs are less actively involved in the rugby game and thus also less active in competing for the ball, which is also verified by the results of this study. From the results with regard to the duration of different intensity bouts, it is also clear that forwards spent less time on low-intensity bouts (33 s *versus* 51 s), although the average time period spent on high-intensity bouts was more or less the same between forwards and backs (39 s *versus* 37 s). This may be an indication of a higher work to rest ratio and less recovery time during rugby union games for the adolescent forwards than for the backs.

Furthermore, the study results show that adolescent forwards spent 39 s on average during a rugby match in the HIZ (92.5-100% of HR_{max}), which would mean that the anaerobic alactic energy system will possibly play an important role in contributing to the energy requirements of the activities that fall within this zone. However, due to the brief periods of rest (± 33-70 s on average at 78-92.4% of HR_{max}) that follow the high-intensity work periods, the body will not have enough time for the total replenishment of the phosphate stores and will therefore be forced to rely more on the anaerobic glycolysis energy pathway for energy delivery (5,14). This is especially true in view of the fact that the forwards will repeat the high-intensity activities numerous times during matches. Backs seem to spend more or less 37 s on average during a rugby match in the HIZ (90.3-100% of HR_{max}), while their rest periods are between 51 s and 60 s (at an intensity of 74.1-90.2% HR_{max}) on average during the match. From these findings it is therefore clear that backs would also primarily depend on the anaerobic lactic system as the primary contributor to energy after the first high-intensity period. In view of the average game-related heart rates of the forwards (172.3 bpm) and backs (165.8 bpm) which show that they spent most of the match time (60.3% and 57.5%) in the MIZ (forwards 88.0% of HR_{max} and backs: 83.3% of HR_{max}), the importance of the aerobic energy system for energy delivery during a rugby match cannot be underemphasised.

A comparison between the match analysis results of junior and senior rugby players with regard to the different positional groups does however suggest that the demands of senior rugby are much higher than adolescent match play. The rule differences that apply to junior and senior rugby matches may possibly explain some of the differences in the match analyses results between these two groups of players. For example, the duration of u/15 matches is 50 min in total with no injury/extra time allowed, compared to 80 min in total with injury/extra time allowed for senior players (23). Also, scrums are not allowed to be pushed further than 1.5 meters towards the opponents' goal line and has to be reset if it wheels more than 45º in u/15 rugby compared to senior rugby where players are allowed to obtain an unlimited scrumming distance when pushing and wheeling the scrum to 90º (13). These differences in match time and the execution of scrums may increase the demands of senior rugby match play when compared to those of junior rugby match play.

To conclude, the research in this study seems to suggest that the position-specific intensities of u/15 high school rugby union matches can be determined and compared by making use of these players' heart rates and standard graded maximal oxygen uptake test values. The above-mentioned discussion also indicates that the last-mentioned match analysis method would probably be more accurate than GPS analysis to analyse junior rugby match intensities. A more accurate reflection of the physical demands placed on junior players during match play will therefore be obtained.

It is in the light of this conclusion that the shortcomings of the study are examined. The small group sizes in this study could have caused outliers to have influenced the average heart rates and standard graded maximal oxygen uptake test values more than would have been the case with larger group sizes. Apart from this, only the data of players distributed over a small geographical area in South Africa were utilized. Generalization of the results to the whole of South Africa or world would therefore not be accurate. The use of a motorised treadmill which generates the running speed at which the player must run as well as the linear movements that take place during the standard incremental treadmill test are very different from the movements taking place during actual match play situations. Therefore it would be advisable to make use of a more rugby-specific incremental test for determining the different heart rate-intensity zones.

PRACTICAL APPLICATIONS

From the study results it is clear that positional differences in the intensities of u/15 high school rugby union matches can be determined by making use of heart rates and standard incremental maximal oxygen uptake test values. This rugby match analysis method can also be used for determining individual players' specific training heart rate zones so that it can be implemented during rugby union training sessions so that the desired physiological responses can be obtained. In this regard the position-specific results suggest that adolescent forwards must repeat high-intensity activities (92.5-100% of HR_{max}) of 39 s on average at a time during training, interspersed with brief periods of rest (± 33 s -70 s) at a heart rate-intensity of 78 - 92.4% of HR_{max} during training. Backs must spend more or less 37 s on average at a time on high-intensity activities (90.3-100% of HR_{max}), interspersed with brief rest periods (± 51 s -60 s) which take place at an intensity of 74.1-90.2% HR_{max} on average during training. However, both player groups must also be conditioned to maintain 60 s - 70 s of activities at a moderate heart rate-intensity (forwards 88.0% of HR_{max} and backs: 83.3% of HR_{max}) for prolonged periods of time.

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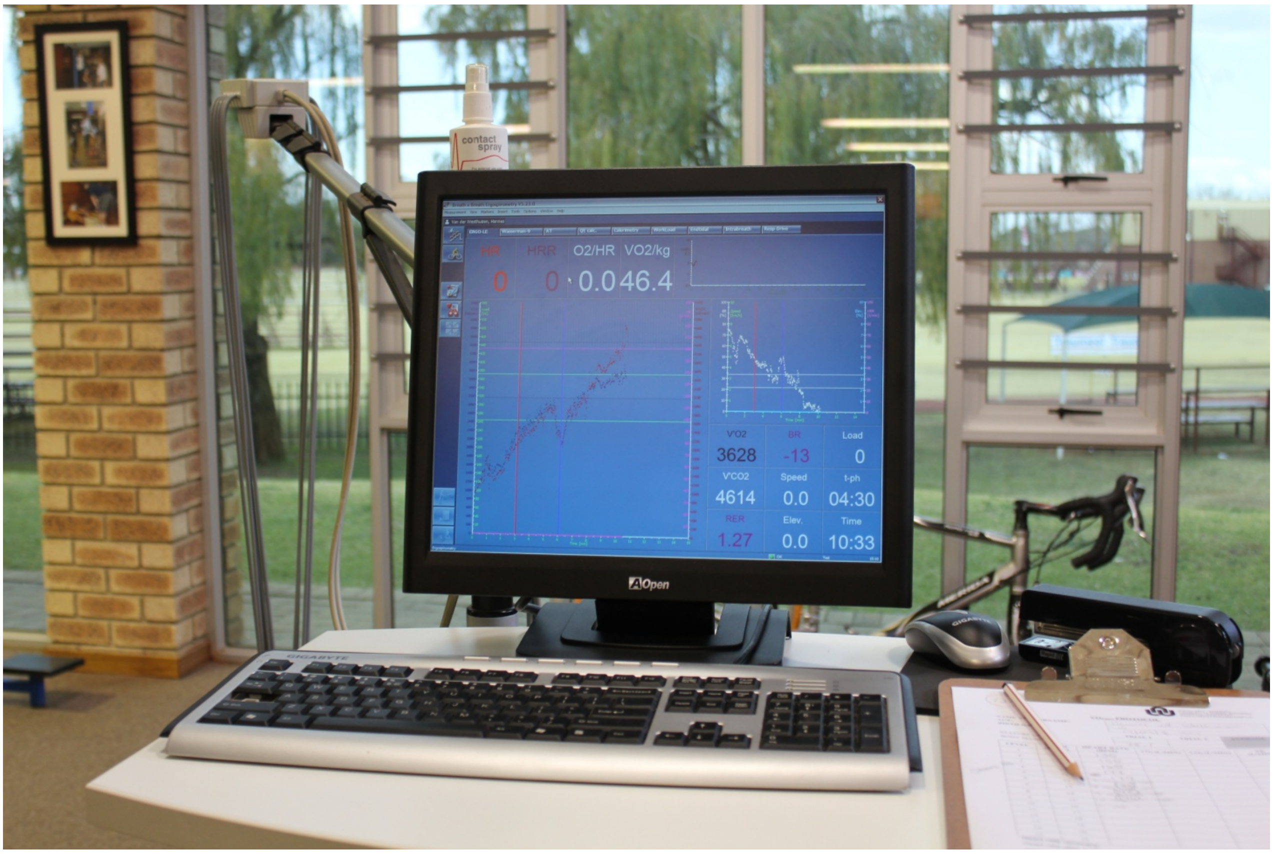
CHAPTER: 5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5 SUMMARY, CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS

1. SUMMARY

The purposes of this study were firstly, to determine the heart rate and standard graded maximal oxygen uptake test values of u/15 high school rugby players; secondly, to determine the intensities of u/15 high school rugby union games when making use of heart rates and standard graded maximal oxygen uptake test values; thirdly, to determine whether the absolute and relative total match time spent in each heart rate-intensity zone during u/15 high school rugby games are significantly different when making use of heart rates and standard graded maximal oxygen uptake test values; fourthly, to determine the significant positional differences in the heart rate and standard incremental maximal oxygen uptake test values of u/15 high school rugby players; and lastly, to determine the significant positional differences in the intensities of u/15 high school rugby union games when making use of heart rates and standard incremental maximal oxygen uptake test values. Chapter 1, the introduction provided a brief problem statement that culminated in the research questions, objectives and the related hypotheses of the study as well as the structure of this dissertation.

Chapter 2 consisted of a literature review titled “The different methods to analyse the game intensities of rugby union”. The chapter provided a brief discussion of different rugby union match analysis methods that have until now been used in rugby analysis-related studies on senior and junior rugby players as well as the research results of these studies. Furthermore, the shortcomings with regard to the use of each of the literature-identified methods were highlighted. This was followed by an explanation of the rule differences between senior and junior rugby and a comparison between the match analyses' results of each of the literature-identified rugby analysis methods between senior and junior rugby matches.

The literature review revealed that several methods for use in the match analyses of rugby union are available and include the following: notational analysis, time-motion analyses, GPS analyses, blood lactate monitoring and heart rate recording and analyses as well as the combined use of heart rates and graded maximal test values. The results of TMA studies on rugby union (elite provincial level) showed that the majority of game time is spent on low-intensity activities (LIA) (57% to 95%), whereas high-intensity activities (HIZ) make up 5.3% to 33.5% of the total match time. GPS monitoring showed the total percentages of match time spent in LIA to be 92-95% and in HIA 5-9%. One study using heart rate measurements found that forwards spent 57.3% of the total match time on HIA (above 95% of HR_{max}) compared to the backs that spent 37% of the total match time on HIA. Studies that measured the blood lactate levels of players reported blood lactate values of above the lactate threshold (LT) level in some instances, and in other instances below the LT level for both forwards and backs. In a study where a combination of methods was used it was observed that forwards spent 20% of the match time at 95% of the HR_{max} in HIA, whereas the backs spent most of the match time at 75% to 85% of the HR_{max}. One study that used heart rates and graded maximal test values concurrently divided match intensities into low (LIZ), moderate (MIZ) and high-intensity zones (HIZ). Results of this study showed that the forwards spent 11.3% on average in the LIZ and the backs 33.6%; forwards spent 34.1% of the total match time in the MIZ compared to the backs that spent 33.1%; and forwards spent 54.6% of match time in the HIZ compared to the backs that spent 32.7% of match time in this zone.

Each of the TMA, GPS, HR and blood lactate measuring methods have their limitations, with TMA that only measures visible actions, incorrectly categorising real (static) exertion type of activities and being prone to measurement errors due to the subjectivity of the observations. GPS measures speed of movement and accurately determines total distance covered during match play but does not reflect the actual exertion levels of players and may be inaccurate when measuring the speed of activities executed over distances below 30 meters. Blood lactate can be regarded as a rather accurate method for identifying time periods when the exertion is above or below the lactate threshold level, but is only accurate for activities performed immediately before the measurement had taken place. These limitations with regard to the application of heart rates, blood lactate and TMA for determining rugby game intensities have compelled researchers to also investigate the use of a combination of methods in order to increase the accuracy and validity of game analysis results.

Thus far, only three groups of authors have reported on the game analysis results of junior rugby. An analysis of the differences in the game analysis results of junior and senior rugby players revealed that demands of senior rugby are much higher than those of junior rugby union. These differences in the game analysis results between the two mentioned groups of players highlight the importance of discriminating between the match demands of junior and senior players. Rule differences which dictate a shorter total match length for junior rugby and shorter duration of and less taxing scrums for juniors stress the need for more rugby union match analysis studies on junior rugby players in order to more accurately determine the energy requirements and match demands of this group of players in order to enable coaches and sport scientist to set more specific training guidelines.

Chapter 3 comprises the first article, titled "Determining adolescent boys' rugby union game intensities using heart rates and graded maximal test values", and was compiled according to the guidelines of the Journal of Strength and Conditioning Research. The purposes of this article were firstly, to determine the heart rate and standard graded maximal oxygen uptake test values of u/15 high school rugby players; secondly, to determine the intensities of u/15 high school rugby union games when making use of heart rates and standard graded maximal oxygen uptake test values; and thirdly, to determine whether the absolute and relative total match time spent in each heart rate-intensity zone during u/15 high school rugby games are significantly different when making use of heart rates and standard graded maximal oxygen uptake test values. The results firstly indicated that adolescent rugby players showed an average $\dot{V}O_{2max}$ value of 49.20 ml·kg^{-1}·min^{-1}, which they obtained at an average $\dot{V}O_{2max}$ HR value of 196.94 bpm; a VT of 77.67% (154.33 bpm) of the HR_{max} that was reached at a $\dot{V}O_2$ of

31.08 $ml \cdot kg^{-1} \cdot min^{-1}$; a RCP at 87.38% of $\dot{V}O_{2max}$ (42.80 $ml \cdot kg^{-1} \cdot min^{-1}$) at an average heart rate of 184.4 bpm, which was determined to be 92.72% of the HR_{max} during a standard graded maximal oxygen uptake test. Secondly, the heart rates for the three intensity zones were determined to be: <154.33 bpm (low-intensity zone), 154.33-184.35 bpm (moderate-intensity zone) and >184.35 bpm for the high-intensity zone. By using the last-mentioned heart rate zones the researchers revealed that the adolescent players spent most of match time in the moderate-intensity heart rate zone (27 min and 49 s, 56.34% of the total match time), followed by the high-intensity zone (10 min and 55 s, 23.03% of the total match time) and the low-intensity zone (9 min and 6 s, 19.95% of the total match time). However, the average duration of low-intensity bouts was higher (67 s) than the low (40 s) and high - (39 s) intensity bouts respectively. Lastly, significant differences were observed for all the above-mentioned values between the low and moderate-intensity as well as between the moderate and high-intensity zones. However, no significant differences were found between the absolute and relative total match time spent in the low and high-intensity zones.

Chapter 4 comprised the second article, titled “Heart rate and graded maximal test values to determine positional Rugby Union game intensities of adolescent boys”, and was also compiled according to the guidelines of the Journal of Strength and Conditioning Research. The purposes of this article were firstly, to determine the significant positional differences in the heart rate and standard incremental maximal oxygen uptake test values of u/15 high school rugby players and lastly, to determine the significant positional differences in the intensities of u/15 high school rugby union games when making use of heart rates and standard incremental maximal oxygen uptake test values. The results showed that the backs obtained significantly higher average HR values at the VT and HR values for the low and moderate-intensity zones as well as significantly lower average $\dot{V}O_2$ at RCP than the forwards. With regard to the match analysis-related results, the forwards obtained significantly lower values for the total time and relative total time spent in the low-intensity zone than the backs. No other significant differences were found between two positional groups with regard to game-intensity zones.

2. CONCLUSIONS

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

Hypotheses 1 and 4:

Due to the fact that no research exists that has made an attempt to use the mentioned technique to classify the different exercise-intensity heart rates and to determine the game intensities of high school rugby union games positionally, no hypotheses were set for the first and fourth purposes of the study. However, the study results indicated that adolescent rugby players showed an average $\dot{V}O_{2max}$ value of 49.20 ml·kg^{-1}·min^{-1}, which they obtained at an average $\dot{V}O_{2max}$ HR value of 196.94 bpm; a VT of 77.67% (154.33 bpm) of the HR_{max} reached at a $\dot{V}O_2$ of 31.08 ml·kg^{-1}·min^{-1}; a RCP at 87.38% of $\dot{V}O_{2max}$ (42.80 ml·kg^{-1}·min^{-1}) at an average heart rate of 184.4 bpm, which was determined to be 92.72% of the HR_{max} during a standard graded maximal oxygen uptake test. Furthermore, adolescent backs obtained significantly higher average HR at the VT than the forwards, whereas the forwards obtained significantly higher average $\dot{V}O_2$ at RCP than the backs. These results would suggest that the backs seem to be more economical at higher exercise intensities than the forwards that are more economical at lower intensities. These results are probably related to the fact that a significantly higher body mass was observed for the forwards than for the backs.

Hypothesis 2:

Under 15 high school rugby union games will be characterised by more low and moderate-intensity activities than high-intensity activities when making use of heart rates and standard graded maximal oxygen uptake test values. The study results revealed that the adolescent players spent the majority of match time in the moderate-intensity heart rate zone (27 min and 49 s, 56.34% of the total match time), followed by the high-intensity zone (10 min and 55 s, 23.03% of the total match time) and the low-intensity zone (9 min and 6 s, 19.95% of the total match time). However, the average duration of low-intensity bouts was higher (67 s) than the low (40 s) and high- (39 s) intensity bouts, respectively. Therefore in view of the results that rugby games were characterised by more moderate compared to high-intensity activities, but more time was spent in the high-intensity than in the low-intensity heart rate zone, the hypothesis can only be partly accepted.

Hypothesis 3:
Significant differences will exist with regard to the absolute and relative total match time spent in each heart rate-intensity zone during u/15 high school rugby games when making use of heart rates and standard graded maximal oxygen uptake test values. Significant differences were observed for the absolute and relative total match time spent in each heart rate-intensity zone between the low and moderate-intensity as well as between the moderate and high-intensity zones. Again, the set hypothesis can only be partly accepted due to the fact that no significant differences were found for the absolute and relative total match time spent in the low and high-intensity heart rate zones respectively.

Hypothesis 5:
Under 15 forwards will obtain significantly higher values for the amount and percentage of time spent in the high-intensity heart rate zone than the backs, whereas the u/15 backs will obtain significantly higher values for the amount and percentage of time spent in the low-intensity heart rate zone than the forwards during high school rugby union games when making use of heart rates and standard incremental maximal oxygen uptake test values. According to the study results, the only variables for which the backs obtained significantly higher values than the forwards (forwards: 05 min 22 s; backs: 15 min 11 s and forwards: 12.5%; backs: 26.4%), were the amount and percentage of time spent in the low intensity heart rate zone. No significant differences were reported for the amount and percentage of time spent in the high-intensity heart rate zone between the two positional groups, which would again mean that the set hypothesis can only be partially accepted.

3. LIMITATIONS AND RECOMMENDATIONS

This was only the second study that has made use of the heart rate and standard graded maximal oxygen uptake test values for determining the game intensities and game-intensity differences between groups of rugby union players but was, however, the first to do so on adolescent boys. The study has also proved that the combined use of heart rates and graded maximal test values to determine adolescent rugby union match intensities is legitimate. However, certain shortcomings need to be considered when interpreting the study results:

- Firstly, the small group sizes in this study could have caused outliers to have influenced the average heart rates and standard graded maximal oxygen uptake test values more than would have been the case with larger group sizes. Hence further research of this nature must focus on larger group sizes.
- Secondly, the adolescent players targeted for this study were players from one school, in one province of South Africa, which means that the results cannot be generalized to all adolescent rugby players. For generalization purposes it would therefore be advisable to include players that are situated across a larger geographical area
- Thirdly, from a physiological viewpoint, the standard incremental treadmill test may not be the most suitable (sport-specific) method for determining the heart rate-intensity zones for use in analysing the rugby union match demands. The use of a motorised treadmill which generates the running speed at which the player must run as well as the linear movements that take place during the standard incremental treadmill test are very different from the movements taking place during actual match play situations. Therefore it would be advisable to make use of a more rugby-specific incremental test to determine the different heart rate-intensity zones. In this regard, a field test such as the Yo-Yo intermittent recovery (IR) test which can be performed while wearing a portable gas analyser apparatus may serve as a more sport-specific test to measure the direct $\dot{V}O_2$ and the two physiological gas exchange points of rugby players.
- Lastly, the skill level of the opponents, the importance of the match outcome and the weather conditions were not considered in the analysis of the heart rate values of the individual players. These factors may possibly influence the heart rate values during a rugby union game and need to be considered.

APPENDIX A:

General information, informed consent and heart rate and graded maximal test values protocol to determine rugby game intensities.

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
POTCHEFSTROOMKAMPUS

GENERAL INFORMATION

Please write clearly!

1. GEOGRAPHICAL INFORMATION

1.1 Surname:	Initials	First Name

1.2 Age:

Years:	Months:

1.3 Birth date:

Year:	Month:	Day:

1.4 Permanent residential address in South Africa:

____
____
____
____
____
____

1.5 Permanent postal address in South Africa:

____
____
____
____

____
____
____

1.6 Phone numbers:

Home:	Work:
Fax:	Cell:
E-mail:	

1.7 Ethnic group

White	Coloured	Black	Indian

In the next few question cross out the answers that are applicable to you!!

2. INFORMATION REGARDING TRAINING HABITS

2.1 Years you've been playing rugby - since you started to specialise in rugby.

1-2 years	3-4 years	5-6 years	7-8 years	8-9 years	10-11 years	12 or more

2.2 Frequency of training - how many days per week do you normally train?

1 day	2 days	3 days	4 days	5 days	6 days	7 days

2.3 Frequency of training - how many days per week do you normally do weight training?

1 day	2 days	3 days	4 days	5 days	6 days	7 days

2.4 Frequency of training - how many days per week do you normally have field sessions?

1 day	2 days	3 days	4 days	5 days	6 days	7 days

2.5 How many hours per day do you normally train?

1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 or more

2.6 How many hours per day do you normally spend on weight training?

1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 or more

2.7 How many hours per day do you normally spend on training on the field?

1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 or more

2.8 Do you spend any time on psychological preparation for rugby and competitions?

Never	*Sometimes	*Often	*Always

*** Please specify the type of psychological preparation you do if you marked any of these three options:**

____ ____ ____ ____ ____ ____ ____ ____________________________________

3. MEDICAL INFORMATION

3.1 Please describe any past or current musculoskeletal conditions you have incurred (i.e., muscle pulls, sprains, fractures, surgery, back pain, or any general discomfort):

Head/Neck: ____________________ ____________________ ____________________ ____________________ ____________
Shoulder/Clavicle: ____________________ ____________________ ____________________ ____________________ ____________________ ____________
Arm/Elbow/Wrist/Hand: ____________________ ____________________ ____________________ ____________________ ____________________ ____________
Back: ____________________ ____________________ ____________________ ____________________ ____________
Hip/Pelvis: ____________________ ____________________ ____________________ ____________________ ____________
Thigh/Knee: ____________________ ____________________ ____________________ ____________________ ____________________

____
Lower leg/Ankle/Foot:

3.2 Please list any medication being taken currently and/or taken during the last year:

3.3 List any other illness or disorder that a physician has told you of:

4. COMPETITION DATA

4.1 At what level are you competing this year?

4.2 What is the highest level that you competed at last year?

School:	Provincial:	National:

4.3 How many matches, approximately, have you played?

School:	Provincial/National:

4.4 What were the highest achievements you attained the past two years?

Achievement	Competition	Date

4.5 What position/s do you usually play during matches?

1.
2.
3.

CONFIDENTIAL

Informed consent form

PART 1

1. **School/Institute:**
   School for Biokinetics, Recreation and Sport Science

2. **Title of project/trial:**
   The use of heart rates and graded maximal test values to determine the rugby union game intensities of high school boys.

3. **Full names, surname and qualifications of project leader:**
   Ben Coetzee, B.Sc., B.Sc. (Hons), M.Sc. and Ph.D

4. **Rank/position of supervisor:**
   (Professor, Lecturer, Research scientist etc.)

   Senior Lecturer

5. **Full names, surname and qualifications of supervisor of the project:**
   (Complete only if not the same person named in 4.)

   Same as above.

6. **Name and address of supervising medical officer *(if applicable)*:**
   Not applicable

7. **Aims of this project**
   The aims of this project are:

- To measure the heart rates and graded maximal test values of u/15 high school rugby union players;
- To determine the intensities of u/15 high school rugby games when making use of heart rates and graded maximal test values;
- To determine whether significant differences occur in the game intensities between the first and second halves of u/15 high school rugby matches;
- To determine whether significant positional differences occur in the rugby game intensities between the u/15 high school forwards and backs.

8. Explanation of the nature of all procedures, including identification of new procedures:

a) *Collection procedures and selection of rugby players.*

The test subjects will consist of thirty high school u/15 first and second rugby team players of one of the high schools in the Potchefstroom district. For the players' data to be included in the study, they need to spend at least 80% of the game on the field; they must complete a graded maximal running test at least a week after or before the game; they may not experience any health or injury related problems; they must form part of the u/15 first or second rugby union teams of the high school targeted for the study. More or less 30 players' (15 from each team) heart rates will be monitored for the duration of several games. The players will be divided into two positional groups for each of the games, namely forwards, which will consist of the eight front line players, and backs, which will consist of the seven back line players.

b) *Procedures*

i. Demographic and general information questionnaire:

The players' demographic and personal information will be collected by means of a demographic and general informational questionnaire. The players' exercise habits, injury occurrence and competing levels will also be obtained by means of this questionnaire.

ii. Standard incremental maximal oxygen uptake test (SIMOUT):

A standard incremental maximal oxygen uptake (VO_{2max}) test (SIMOUT) will be conducted by means of open-circuit spirometry. Each of the players will perform the SIMOUT to the point of exhaustion on a Woodway Pro XL treadmill (WOODAY, W229 N591, Foster Ct, Waukesha, WI). At commencement of the SIMOUT the first 2 minutes will be performed at 8 km/h after which the treadmill speed will be increased to 10 km/h and by 1 km/h every minute after the first two minutes. Expired air will continuously be 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 (VO_2), carbon dioxide production (VCO_2), minute ventilation (Ve) and the respiratory exchange ratio (R) will be calculated every 5 seconds by an on-line computer system. The Oxycon Pro will be calibrated according to the manufacturer's specifications at the beginning of each test day. The test will be stopped if the rugby player indicates that it must be stopped or if the criteria for reaching the VO_{2max} value is achieved (Davis, 2006:15; McArdle *et al*., 2001:233).

iii. Rugby game heart rates:

Data will be collected via the measuring of the players' match play heart rates during several different matches. The players' heart rates will be measured with the use of a Polar Team^2 Pro Electro system (Kempele, Finland) and will be recorded on a laptop computer with the Polar Team^2 Pro software program. An electrode belt will be strapped around the chest at the lower sternum of each player before the start of each match. The players will undergo several days of testing. An incremental test will be performed several times in the week before each match.

9. Description of the nature of discomfort or hazards of probable permanent consequences for the subjects which may be associated with the project:
(Including possible side-effects of and interactions between drugs or radio-active isotopes which may be used.)

The subjects may experience a bit of muscle discomfort and nausea.

10. Precautions taken to protect the subjects:
The players will perform a proper warm-up before the SIMOUT commences and the testing procedures and methods will be thoroughly explained to each of the players.

11. Description of the benefits which may be expected from this project:
The results might point to possible rugby game intensities, as well as game intensity differences between playing positions. This will also help coaches to plan their season correctly in order to optimize performance for their players.

12. Alternative procedures which may be beneficial to the subjects:
(Complete only if applicable.)

The physiological measurements will give the players and the researcher an indication of the importance of different energy systems contributing to rugby games.

Signature:... **Date:** ....

Project leader: Dr Ben Coetzee

PART 2

To the subject signing the consent as in part 3 of this document:

You are invited to participate in a research project as described in paragraph 2 of Part 1 of this document. It is important that you read/listen to and understand the following general principles, which apply to all participants in this research project:

1. Participation in this project is voluntary.
2. It is possible that you personally will not derive any benefit from participation in this project, although the knowledge obtained from the results may be beneficial to other people.
3. You will be free to withdraw from the project at any stage without having to explain the reasons for your withdrawal. However, we would like to request that you would rather not withdraw without a thorough consideration of your decision, since it may have an effect on the statistical reliability of the results of the project.
4. The nature of the project, possible risk factors, factors which may cause discomfort, the expected benefits to the subjects and the known and the most probable, permanent consequences which may follow from your participation in this project, are discussed in Part 1 of this document.
5. We encourage you to ask questions at any stage about the project and procedures to the project leader or the personnel, who will readily give more information. They will discuss all procedures with you.
6. If you are a minor, we need the written approval of your parent or guardian before you may participate.

7. We require that you indemnify the University from any liability due to detrimental effects of treatment by University staff or students or other subjects to yourself or anybody else. We also require indemnity from liability of the University regarding any treatment to yourself or another person due to participation in this project, as explained in Part 1. Lastly it is required to abandon any claim against the University regarding treatment of yourself or another person due to participation in this project as described in Part 1.

PART 3

Consent

Title of the project: The use of heart rates and graded maximal test values to determine the rugby union game intensities of high school boys.

I, the undersigned ………………………………………………………………… (Full names) read/listened to the information on the project in PART 1 and PART 2 of this document and I declare that I understand the information. I had the opportunity to discuss aspects of the project with the project leader and I declare that I participate in the project as a volunteer. I hereby give my consent to be a subject in this project.

I indemnify the University, also any employee or student of the University, of any liability against myself, which may arise during the course of the project.

I will not submit any claims against the University regarding personal detrimental effects due to the project, due to negligence by the University, its employees or students, or any other subjects.

…………………………………………

(Signature of the subject)

Signed at ....on ………………………………………..

Witnesses

1. ....

2. ....

Signed at .... on …………………………………

For non-therapeutic experimenting with subjects under the age of 18 years the written approval of a parent or guardian is required.

I, …………………………………………………. .... (Full names)

Parent or guardian of the subject named above, hereby give my permission that he/she may participate in this project and I also indemnify the University and any employee or student of the University, against any liability which may arise during the course of the project.

Signature: .... Date: ……………………………

Relationship: ……………………….

APPENDIX B:

VO_{2max} PROTOCOL

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
POTCHEFSTROOMKAMPUS

VO_{2max} PROTOCOL

NAME AND SURNAME:			
AGE:			
BIRTH DATE:			
	TRIAL 1	**TRIAL 2**	**AVERAGE**
STATURE (cm)			
BODY MASS (kg)			

VO_{2max}

LEVEL	SPEED (KM/H)	HEART RATE (BPM)	VO_2 (L/MIN)	CO_2 (L/MIN)	VE(L/MIN)
1	8				
2	10				
3	11				
4	12				
5	13				
6	14				
7	15				
8	16				
9	17				
10	18				
11	19				
12	20				
13	21				

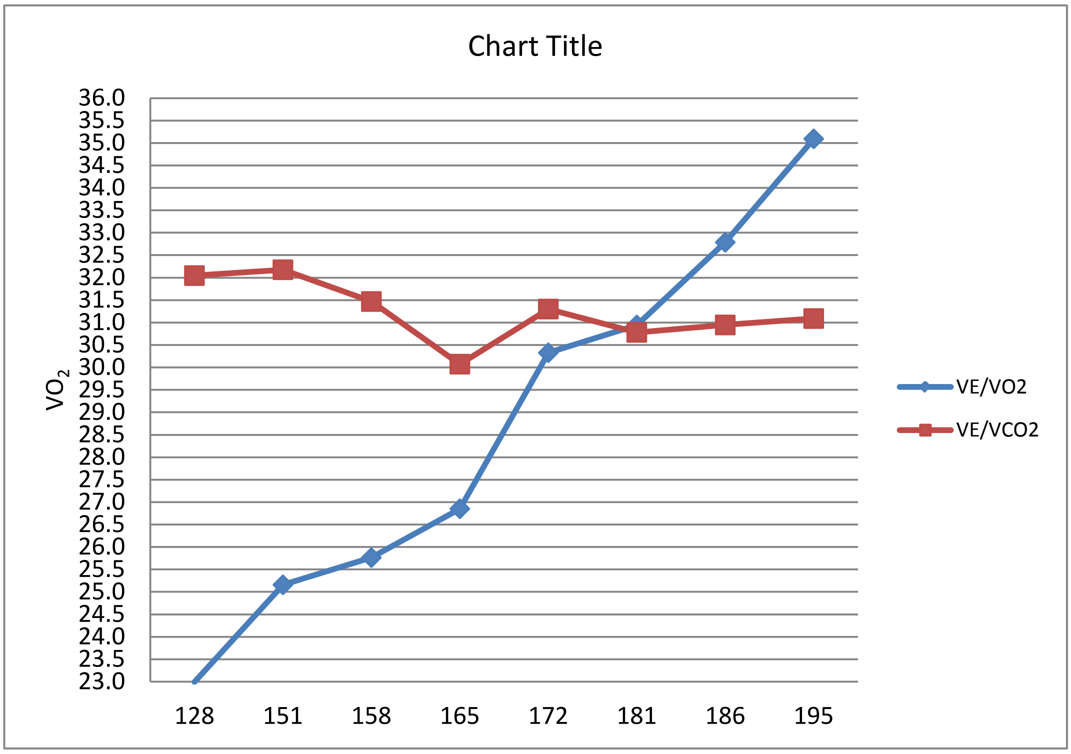
APPENDIX C:

SPREAD SHEET RESULTS OF VO_{2MAX} VT/RCP TEST

	Player 1	Test 2										
level	HT	Ve	VO2	VE/VO2	VE/VCO2	Ve	VCO2	Ve	VE/VO2	VE/VCO2	VO2 MAX
1	128	39	1.696	23.0	32.0	39	1.217	**37**	**2.2**	**0.1**	18.3
2	**151**	**76**	**3.021**	**25.2**	**32.2**	**76**	**2.362**	**5**	**0.6**	**-0.7**	**32.7**
3	158	81	3.144	25.8	31.5	81	2.574	14	1.1	-1.4	32.9
4	165	95	3.538	26.9	30.1	95	3.159	21	3.5	1.2	38.3
5	172	116	3.825	**30.3**	**31.3**	116	3.706	11	0.6	-0.5	41.4
6	**181**	**127**	**4.104**	**30.9**	**30.8**	**127**	**4.126**	**13**	**1.8**	**0.2**	**44.4**
7	186	140	4.27	32.8	30.9	140	4.524	11	2.3	0.1	46.2
8	195	151	4.303	35.1	31.1	151	4.857				**46.6**

VT **151** **RCP** **181**

VT % $VO_{2\,MAX}$ 70.17% RCP % $VO_{2\,MAX}$ 95.3%



APPENDIX D:

SUBMISSION GUIDELINES FOR AUTHORS AND AN EXAMPLE OF AN ARTICLE:

JOURNAL OF STRENGTH AND CONDITIONING RESEARCH

Authors' guidelines for JSCR

Short Overview:

You must submit the cover letter, copyright release, and manuscript separately to separate identifying information from the manuscript.

Manuscript must match JSCR formatting, including terminology use and units.

Please attempt to keep all figures and tables in a single file (instead of submitted as separate attachments). We prefer that each diagram be pasted into a PowerPoint presentation. Ensure all figures are labelled and referenced in the manuscript.

IRB approval must be mentioned.

If you use Microsoft Word, save in the .doc format.

JSCR publishes original investigations, reviews, symposia, research notes, and technical and methodological reports contributing to the knowledge about strength and conditioning in sport and exercise. Manuscripts are subjected to a "double blind" peer review by at least two reviewers who are experts in the field. Editorial decisions will be based on the quality, clarity, style, and importance of the submission relative to the goals and objectives of the NSCA and the journal. Tips for writing a manuscript for the *JSCR* can be found at **http://www.nsca-lift.org/publications/JSCRtips.shtml**. Please read this document carefully prior to preparation of a manuscript.
Important Notice: Manuscripts not formatted according to author guidelines will be returned to the corresponding author.

Contents:

Editorial Mission Statement

The editorial mission of the *JSCR*, formerly the *Journal of Applied Sport Science Research* (JASSR), is to advance the knowledge about strength and conditioning through research. Since 1978 the NSCA has attempted to "bridge the gap" from the scientific laboratory to the field practitioner. A unique aspect of this journal is that it includes recommendations for the practical use of research findings. While the journal name identifies strength and conditioning as separate entities, strength is considered a part of conditioning. This journal wishes to promote the publication of peer-reviewed manuscripts that add to our understanding of conditioning and sport through applied exercise and sport science.

Submission Process

1) Author submits all required materials, including copyright form, IRB, and separate cover letter.
2) Completed submission is sent out to two reviewers.
3) Reviewers critique article and send it back to the editorial office for processing.
4) After initial review, Editor-in-Chief releases reviews to authors.
5) Authors are asked to respond to reviewers and make necessary corrections.
6) Article is sent out for re-review.
7) Editor-in-Chief may accept, reject, accept with minor alterations, or sent out for third review.
8) If accepted, author must submit final version. Version will be added to "in-press" queue with publisher.
9) Prior to publication, publisher will sent galleys to authors. No edits may be made after galleys are approved.
10) Article is printed to JSCR.

Submission Categories

Original Research

JSCR publishes research that addresses a wide variety of questions concerning conditioning, sport, and exercise demands. This ranges from research on the effects of training programs on physical performance and function to the underlying biological basis for exercise performance. Research is appropriate from a number of disciplines attempting to gain insights about sport, sport demands, conditioning, and exercise such as biomechanics, exercise physiology, motor learning, nutrition, and psychology. A primary goal of *JSCR* is to provide an improved scientific basis for conditioning practices.

Symposia

JSCR publishes symposia that are related to the journal's mission. A symposium is a group of articles by different authors that address an issue from various perspectives.

Brief Reviews

JSCR publishes brief reviews by scientific experts in the field. The reviews should provide a critical examination of the literature and integrate the results of previous research in an attempt to educate the reader as to the basic and applied aspects of the topic. We are especially interested in applied aspects of the reviewed literature.

Scientific Comments, Methodological Reports, and Research Notes

JSCR also publishes short research reports, technical reports and short research communications, and strongly encourages the submission of manuscripts detailing methodologies that help to advance the study of strength and conditioning.

Manuscript Clarifications

Manuscript Clarifications will be considered and will be published "on-line" if accepted. Not all requests for manuscript clarifications will be published due to costs or content importance. Each will be reviewed by a specific sub-committee of Associate Editors to determine if it merits publication. A written review with needed revisions will be provided if it merits consideration. Clarifications questions are limited to 400 words and should only pose professional questions to the authors and not editorial comments (as of 19.2). If accepted, a copy will be sent to the author of the original article with an invitation to submit answers to the questions in the same manner again with a 400 word limit.

Manuscript Submission Guidelines

Authors should submit the original file in one of the following formats: Microsoft® Word® (.doc, .rtf, .txt), Corel® WordPerfect® (.wpd, .rtf, .txt), or Adobe® Acrobat® (.pdf).

You must submit the cover letter, copyright release, and manuscript separately to separate identifying information from the manuscript.

Manuscript must match JSCR formatting, including terminology use and units.

Please attempt to keep all figures and tables in a single file (instead of submitted as separate attachments). We prefer that each diagram be pasted into a PowerPoint presentation. Ensure all figures are labeled and referenced in the manuscript.

IRB approval must be mentioned.

If you use Microsoft Word, save in the .doc format.

Cover Letter: A cover letter must accompany the manuscript and state the following: "This manuscript is original and not previously published, nor is it being considered elsewhere until a decision is made as to its acceptability by the *JSCR* Editorial Review Board." Please include the corresponding author's full contact information, including address, email, and phone number.

Compliance with NIH and Other Research Funding Agency Accessibility Requirements: A number of research funding agencies now require or request authors to submit the post-print (the article after peer review and acceptance but not the final published article) to a repository that is accessible online by all without charge. As a service to our authors, LWW will identify to the National Library of Medicine (NLM) articles that require deposit and will transmit the post-print of an article based on research funded in whole or in part by the National Institutes of Health, Wellcome Trust, Howard Hughes Medical Institute, or other funding agencies to PubMed Central. The revised Copyright Transfer Agreement provides the mechanism.

Copyright Form: The National Strength and Conditioning Association must receive in writing the exclusive assignment of copyright from all authors at the time of manuscript submission. This form can be found at **http://journals.lww.com/nsca-jscr/Documents/copyrightTransfer.pdf**. If only one author signs the copyright assignment form, such author warrants that he/she is the duly authorized agent of all other co-authors. Your manuscript will not be published if a signed copyright release form is not returned. Please return your original signed copyright assignment form to the editorial office at the time you submit your manuscript. Please keep a copy for your records. Manuscripts are considered for publication on the condition that they are contributed solely to the *JSCR* and, therefore, have not been and will not be published elsewhere, in part or in whole. Manuscripts containing data that have been posted to the Internet for public access will not be considered for publication. Copyright forms can be faxed to 860-486-6898 or 860-486-1123.

IRB: The NSCA and the Editorial Board of the *JSCR* have endorsed the American College of Sports Medicine's policies with regards to animal and human experimentation. Their guidelines can be found online at **http://www.editorialmanager.com/msse/**. Please read these policies carefully. Each manuscript must show that they have had Institutional Board approval for their research and appropriate consent has been obtained pursuant to law. All manuscripts must have this clearly stated in the methods section of the paper or the manuscript will not be considered for publication.

Authorship: All authors should be aware of the publication and be able to defend the paper and its findings and should have signed off on the final version that is submitted. For additional details related to authorship, see "Uniform Requirements for Manuscripts Submitted to Biomedical Journals" at **http://www.icmje.org/**.

Formatting and Units: All manuscripts must be double-spaced with an additional space between paragraphs on 8½ x11-inch paper. The paper should include a minimum of 1-inch margins and page numbers in the upper right corner next to the running head. Please use a font of at least 12. Authors must use terminology based upon the International System of Units (SI). A full list of SI units can be accessed online at **http://physics.nist.gov/**. Manuscript identification numbers (e.g., R-12034) will be assigned to each manuscript, and should be placed on all revised manuscripts and used along with the manuscript title for all communications with the Editorial Office. Any revision should have the revision number placed after the manuscript number, (e.g., R-12034, Revision 1).

Language Use: Again the *JSCR* endorses the same policies as the American College of Sports Medicine in that the language is English for the publication. "Authors who speak English as a second language are encouraged to seek the assistance of a colleague experienced in writing for English language journals. Authors are encouraged to use nonsexist language as defined in the American Psychologist 30:682-684, 1975, and to be sensitive to the semantic description of persons with chronic diseases and disabilities, as outlined in an editorial in *Medicine & Science in Sports & Exercise*®, 23(11), 1991. As a general rule, only standardized abbreviations and symbols should be used. If unfamiliar abbreviations are employed, they should be defined when they first appear in the text. Authors should follow Webster's Tenth Collegiate Dictionary for spelling, compounding, and division of words. Trademark names should be capitalized and the spelling verified. Chemical or generic names should precede the trade name or abbreviation of a drug the first time it is used in the text."

Manuscript Format Guidelines

1. Title Page

The title page should include the manuscript title, brief running head, laboratory(s) where the research was conducted, authors' full name(s) spelled out with middle initials, department(s), institution(s), full mailing address of corresponding author including telephone and fax numbers, and email address, and disclosure of funding received for this work from any of the following organizations: National Institutes of Health (NIH); Welcome Trust; Howard Hughes Medical Institute (HHMI); and other(s).

2. Blind Title Page

A second title page should be included that contains only the manuscript title. This will be used for reviewer copies.

3. ABSTRACT and Key Words

On a separate sheet of paper, the manuscript must have an abstract with a limit of 275 words followed by 3 – 6 key words not used in the title. The abstract should have sentences (no headings) related to the purpose of the study, brief methods, results, conclusions and practical applications. Do not end with statements such as "will be discussed."

4. Text

The text must contain the following sections with titles in ALL CAPS in this exact order:

A. INTRODUCTION

This section is a careful development of the hypotheses of the study leading to the purpose of the investigation. Limit information that is "chapter like" in nature as this is not an exhaustive review of the topic. Focus the studies lending support to your hypothesis(es) and giving the proper context to the problem being studied. In most cases use no subheadings in this section and try to limit it to 4 – 6 concisely written paragraphs.

B. METHODS

Within the METHODS section, the following subheadings are required in the following order: "Experimental Approach to the Problem," where the author(s) show how their study design will be able to test the hypotheses developed in the introduction and give some basic rationales for the choices made for the independent and dependent variables used in the study; "Subjects," where the authors include the Institutional Review Board or Ethics Committee approval of their project and appropriate informed consent has been gained. All subject characteristics that are not dependent variables of the study should be included in this section and not in the RESULTS; "Procedures," in this section the methods used are presented with the concept of "replication of the study" kept in mind. After reading this section another investigator should be able to replicate your study. Under this subheading you can add others but please limit their use to that which makes the methods clear and in order of the investigation (e.g., Biochemical Assays or EMG Analyses); "Statistical Analyses," here is where you clearly state your statistical approach to the analysis of the data set(s). It is important that you include your alpha level for significance (e.g., $P < 0.05$). Please place your statistical power in the manuscript for the n size used and reliability of the dependent measures with intra-class correlations (ICC Rs). Additional subheadings can be used but should be limited

C. RESULTS

Present the results of your study in this section. Put the most important findings in Figure or Table format and less important findings in the text. Do not include data that is not part of the experimental design or that has been published before. Place descriptive data about subjects in the METHODS section under the subheading of Subjects. Make sure that you cite each Figure and Table, and in space between paragraphs indicate roughly where you want each Figure or Table to appear (e.g., Table 1 about here)

D. DISCUSSION

Discuss the meaning of the results of your study in this section. Relate them to the literature that currently exists and make sure that you bring the paper to completion with each of your hypotheses. Limit obvious statements like, "more research is needed."

E. PRACTICAL APPLICATIONS

In this section, tell the "coach" or practitioner how your data can be applied and used. It is the distinctive characteristic of the *JSCR* and supports the mission of "Bridging the Gap" for the NSCA between the laboratory and the field practitioner. This section of the paper should speak directly to this audience and not to the exercise or sport scientist.

5. References

All references must be alphabetized by surname of first author and numbered. References are cited in the text by numbers [e.g., (4,9)]. All references listed must be cited in the manuscript and referred to by number therein. For original investigations, please limit the number of references to fewer than 40 or explain why more are necessary. The Editorial Office reserves the right to ask authors to reduce the number of references in the manuscript. Please check references carefully for accuracy. Changes to references at the proof stage, especially changes affecting the numerical order in which they appear, will result in author revision fees.

End Note Users: The *Journal of Strength & Conditioning Research reference style* may be downloaded for use in the End Note application: ftp://support.isiresearchsoft.com/pub/pc/styles/endnote4/J%20Strength%20Condition%20Res.ens

Below are several examples of references:

Journal Article

Hartung, GH, Blanco, RJ, Lally, DA, and Krock, LP. Estimation of aerobic capacity from submaximal cycle ergometry in women. *Med Sci Sports Exerc* 27: 452-457, 1995.

Book

Lohman, TG. Advances in Body Composition Assessment. Champaign, IL: Human Kinetics, 1992.

Chapter in an edited book

Yahara, ML. The shoulder. In: Clinical Orthopedic Physical Therapy. Richardson, JK and Iglarsh, ZA, eds. Philadelphia: Saunders, 1994. pp. 159-199.

Software

Howard, A. Moments [software]. University of Queensland, 1992.

Proceedings

Viru, A, Viru, M, Harris, R, Oopik, V, Nurmekivi, A, Medijainen, L, and Timpmann, S. Performance capacity in middle-distance runners after enrichment of diet by creatine and creatine action on protein synthesis rate. In: Proceedings of the 2nd Maccabiah-Wingate International Congress of Sport and Coaching Sciences. Tenenbaum, G and Raz-Liebermann, T, eds. Netanya, Israel, Wingate Institute, 1993. pp. 22 - 30.

Dissertation/Thesis

Bartholmew, SA. Plyometric and vertical jump training. Master's thesis, University of North Carolina, Chapel Hill, 1985.

6. Acknowledgements

In this section you can place the information related to Identification of funding sources; Current contact information of corresponding author; and gratitude to other people involved with the conduct of the experiment. In this part of the paper the conflict of interest information must be included. Authors are required to state in the acknowledgments all funding sources, and the names of companies, manufacturers, or outside organizations providing technical or equipment support. In particular, authors should: 1) Disclose professional relationships with companies or manufacturers who will benefit from the results of the present study, and 2) State that the results of the present study do not constitute endorsement of the product by the authors or the NSCA. Failure to disclose such information could result in the rejection of the submitted manuscript.

7. Figures

First, create a page entitled "Figure Legends" in which each of the figure legends are listed. Include this page in your manuscript document. Next, place each of the figures in a PowerPoint presentation if possible. All figures should be labeled and each figure must be referenced in the manuscript. All figures should be professional in appearance. They should also be viable for size reductions to fit manuscript space allocations. One set of figures should accompany each manuscript. Use only clearly delineated symbols and bars.

Electronic photographs copied and pasted into Word and PowerPoint will not be accepted. Images should be scanned at a minimum of 300 pixels per inch (ppi). Line art should be scanned at 1200 ppi. Please indicate the file format of the graphics. We accept TIFF or EPS format for both Macintosh and PC platforms. We also accept image files in the following Native Application File Formats:

Adobe Photoshop (.psd)

Adobe Acrobat (.pdf) (use Press setting under Job Option)

Illustrator (.ai)

Macromedia FreeHand (.fh)

Corel Draw (.cdr)

Canvas (.cvs)

PowerPoint (.ppt)

Word (.doc)

Excel (.xls)

InDesign (.id)

PageMaker (.pmd)

QuarkXPress (.qxd)

If you will be using a digital camera to capture images for print production, you must use the highest resolution setting option with the least amount of compression. Digital camera manufacturers use many different terms and file formats when capturing high-resolution images, so please refer to your camera's manual for more information.

Please also attempt to format tables into the PowerPoint presentation and include a title. If necessary, tables can be added to the end of the manuscript, but must be double-spaced and include a brief title. Provide generous spacing within tables and use as few line rules as possible. When tables are necessary, the information should not duplicate data in the text. All figures and tables must include standard deviations or standard errors.

Color figures. The author may elect to cover the costs of color at the rate of $500 for the first figure within the article, $100 for each additional single-image figure within the same article, or $200 for each additional figure with more than one part (labeled "a," "b," etc.). If the author decides not to pay for color reproduction, they can request that the figures be converted to black and white at no charge.

Manuscript Format Checklist

Approval by Institutional Review Board

Manuscript contains the following sections (in order)

Title Page

Blind Title Page

Abstract and Key Words

Introduction

Methods

Results

Discussion

Practical Applications

References

Acknowledgements

Figure Legends

Figures

Tables

Manuscript Submission Checklist

___ Cover Letter
___ Completed **Copyright Assignment Form**
___ Original Manuscript, including IRB reference and references to all figures.
___ Figures, in a single power point presentation if possible.

Terminology and Units of Measurement

Per the *JSCR* Editorial Board and to promote consistency and clarity of communication among all scientific journals authors should use standard terms generally acceptable to the field of exercise science and sports science. Along with the American College of Sports Medicine's Medicine and Science ins Sport and Exercise, the *JSCR* Editorial Board endorses the use of the following terms and units.

The units of measurement shall be Système International d'Unités (SI). Permitted exceptions to SI are heart rate—beats per min; blood pressure—mm Hg; gas pressure—mm Hg. Authors should refer to the *British Medical Journal* (1:1334 – 1336, 1978) and the *Annals of Internal Medicine* (106:114 – 129, 1987) for the proper method to express other units or abbreviations. When expressing units, please locate the multiplication symbol midway between lines to avoid confusion with periods; e.g., $mL·min^{-1}·kg^{-1.}$

The basic and derived units most commonly used in reporting research in this Journal include the following:

mass—gram (g) or kilogram (kg); force—newton (N); distance—meter (m), kilometer (km); temperature—degree Celsius (°C); energy, heat, work —joule (J) or kilojoule (kJ); power—watt (W); torque—newton-meter (N·m); frequency —hertz (Hz); pressure—pascal (Pa); time—second (s), minute (min), hour (h); volume—liter (L), milliliter (mL); and amount of a particular substance—mole (mol), millimole (mmol).

Selected conversion factors:

1 N = 0.102 kg (force);

1 J = 1 N·m = 0.000239 kcal = 0.102 kg·m;

1 kJ = 1000 N·m = 0.239 kcal = 102 kg·m;

1 W = 1 J·s-1 = 6.118 kg·m·min-1.

When using nomenclature for muscle fiber types please use the following terms. Muscle fiber types can BE identified using histochemical or gel electrophoresis methods of classification. Histochemical staining of the ATPases is used to separate fibers into type I (slow twitch), type IIa (fast twitch) and type IIb (fast twitch) forms. The work of Smerdu et. al (AJP 267: C1723, 1994) indicates that type IIb fibers contain type IIx myosin heavy chain (gel electrophoresis fiber typing). For the sake of continuity and to decrease confusion on this point it is recommended that authors use IIx to designate IIb fibers in theie manuscripts. Smerdu, V., Karsch-Mizrachi I., Campione M., Leinwand L., Schiaffino S. Type IIx myosin heavy chain transcripts are expressed in type IIb fibers of human skeletal muscle. Am J. Physiol. 267 (6 Pt 1):C1723-1728, 1994.

Running Demands and Heart Rate Responses in Men Rugby Sevens

Luis J. Suarez-Arrones,[1,2] Francisco J. Nuñez,[1,2] Javier Portillo,[3,4] and Alberto Mendez-Villanueva[5]

[1]*Faculty of Sport, Pablo de Olavide University, Sevilla, Spain;* [2]*VF Sport, Sevilla, Spain;* [3]*Faculty of Sport Science, Toledo, Spain;* [4]*Spanish Rugby Federation, Madrid, Spain; and* [5]*Physiology Unit, Sport Science Department, ASPIRE, Academy for Sports Excellence, Doha, Qatar*

Abstract

Suarez-Arrones, LJ, Nuñez, FJ, Portillo, J, and Mendez-Villanueva, A. Running demands and heart rate responses in men rugby sevens. *J Strength Cond Res* 26(11): 3155–3159, 2012—The purpose of this study was to examine match running performance and exercise intensity in a Rugby Sevens (7s) team during competitive club-level matches. Time-motion analyses (global position system) were performed on 7 male rugby players during 5 competitive matches in a 2-day tournament. The players covered an average distance of 1,580.8 ± 146.3 m per game (14 minutes). Over this distance, 34.8% (549.7 ± 79.1 m) was spent standing and walking, 26.2% (414.8 ± 105.1 m) jogging, 9.8% (154.6 ± 53.5 m) cruising, 15.5% (244.5 ± 80.1 m) striding, 5% (79.5 ± 37.2 m) high-intensity running, and 8.7% (137.7 ± 84.9 m) sprinting. The average maximal distance of sprints, the number of sprints, the minimum distance of sprint, and the mean sprint distance over the game were 29.5 ± 11.7 m, 7.4 ± 3.9 sprints, 9.1 ± 5.7 m, and 18 ± 7.6 m, respectively. The player's work-to-rest ratio was 1:0.5. For over 75% of the game, the players were exposed to heart rates (HRs) >80% of their maximal HR. There were no statistical differences between the first and second halves in any of the variables analyzed. This study indicates that the physical demands of Rugby 7s are quite different from those encountered in other rugby codes and that the training regimes need to meet the increased overall running demands, the augmented high-intensity running actions, and the reduced work-to-rest ratios.

Key Words GPS technology, match-play demands, football, team sports

Address correspondence to Alberto Mendez-Villanueva, amendezvillanueva@yahoo.com.

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Introduction

Rugby is a contact, team sport made up of different codes such as rugby union, rugby league or rugby sevens (7s). The rugby union and rugby league matches have a duration of 80 minutes (2 halves of 40 minutes) and are played by 15 and 13 players, respectively. In rugby 7s, matches last 14 minutes (2 halves of 7 minutes) and are played by teams consisting of 7 members on a pitch of the same dimensions as the rugby union and under similar laws. The final scores are similar to those of rugby union because the marks are made more often. Recently, the rugby 7s has been voted one of the new Olympic summer sports and will appear in Rio 2016 (9), being this code one of the fastest growing sports.

Although research has established that in all rugby codes the game is characterized by periods of high-intensity intermittent exercise such as sprints, high-intensity running, tackles, or rucks, which are intercalated with periods of low-intensity and rest (10,15), only 1 study (17) has examined the physical demands on players during rugby 7s matches. However, the results of this study are difficult to interpret because the activity profile categorization was based on qualitative criteria (17). Accordingly, the aim of this study was to examine for the first time the match running demands and exercise intensity associated with men's rugby 7s with global position system (GPS) technology.

Methods

Experimental Approach to the Problem

In this investigation, an observational design was used to examine the match running demands and exercise intensity during a men rugby 7s competitive tournament. Seven highly trained players were investigated during 5 competitive club-level matches in the final rounds of the national championship. The tournament investigated was contested in June at the end of Rugby 7s competitive season. All the players belonged to the same team that competed at the highest level in the national league. Portable GPS technology and heart rate (HR) responses were used to assess match running demands and exercise intensity, respectively. Identification of player movement patterns and the associated physiological

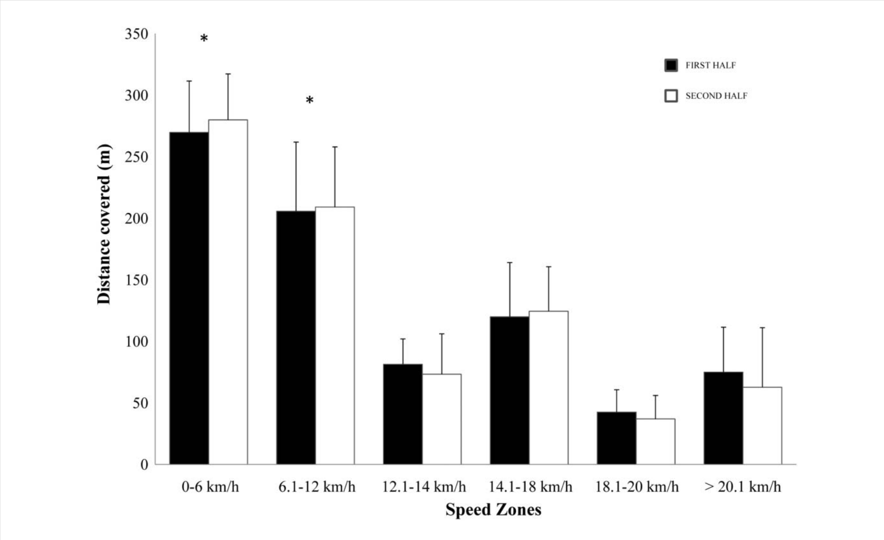

Figure 1. Match running profile during each half for men Rugby 7s players ($n = 17$). Distance in meters covered by the players in designated speed zones. *Significantly higher than any other speed zone ($p < 0.05$). Data are mean ± *SD*.

responses during match play is important for optimizing training prescription and managing player preparation for competition.

Subjects

Time-motion analysis of running activity was collected from 7 highly trained men rugby 7s players (age, 27.4 ± 1.6 years; body mass, 87.9 ± 11.0 kg; height, 180.4 ± 7.8 cm; $\dot{V}O_2max$, 51.6 ± 3.7 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$; 61.6 ± 6.0 $\sum$ skinfolds; mean ± *SD*). All the players participated on average in 13 hours of combined rugby (4 sessions), strength (3 sessions), and conditioning (1–2 sessions) training and competitive play (4–5 rugby 7s games) per week. All the players had a minimum of 5 years of rugby-specific training. Written informed consent was obtained from the players before the investigation. The experimental protocol was approved by the Institutional Ethics Committee.

Table 1. Sprinting performance results obtained during matches in Rugby 7s male players.*

Variables	Halves: First	Halves: Second
Average number of sprints (>20 $km{\cdot}h^{-1}$)	3.8 ± 1.9	3.5 ± 2.0
Average maximal speed ($km{\cdot}h^{-1}$)	25.9 ± 1.7	25.1 ± 3.0
Average maximal sprint distance (m)	31.5 ± 14.2	26.9 ± 9.2
Average minimum sprint distance (m)	10.7 ± 8.5	7.4 ± 2.9
Average sprint distance (m)	19.9 ± 7.8	16.0 ± 7.5

*Data are mean ± *SD*.

Experimental Procedures

Match analyses were performed 2–3 times on each player during a total of 5 club-level matches played over a period of 2 days during the national championship finals. All the matches were played on the same standard outdoor natural grass fields with 7 players per side. Playing time was 2 halves of 7 minutes each. All the players were provided with preexercise and postexercise nutrition and hydration plan developed by the medical staff to ensure adequate nutrient and fluid intake before and between all the matches. Four weeks before the tournament, the players undertook an incremental treadmill test. Pulmonary gas exchange (Oxycon Delta de Jaeger, Hoechberg, Germany) and HR (Polar Team System, Polar Electro Oy, Kempele, Finland) were continuously recorded during the test to determine maximal oxygen uptake ($\dot{V}O_2max$) and maximal HR (HRmax). The protocol began with a 4 minutes of running speed at 8 $km{\cdot}h^{-1}$ followed by stepwise 1-$km{\cdot}h^{-1}$ speed increments every 1 minutes until exhaustion. The $\dot{V}O_2max$ was defined as the highest 30-second average recorded during the incremental treadmill test. The HRmax was defined as the highest 5-second average recorded during the incremental treadmill test.

Activity Pattern Measurements

A GPS unit capturing data at 1 Hz (SPI Elite, GPSports, Canberra, Australia) was fitted to the upper back of each player using an adjustable neoprene harness. This GPS system uses signals from at least 3 Earth-orbiting satellites to determine the players' position at a given time and therefore allow the calculation of movement speeds and distance traveled (8,12). Despite a possible underestimation of high-intensity running distance with the time resolution of 1 Hz, good accuracy (r = 0.97) (2) and reliability (coefficient of variation = 1.7% [2] and 2.3% [3]) have been reported for the assessment of peak sprinting speed for this GPS device compared to a infrared timing system. Moreover, in the absence

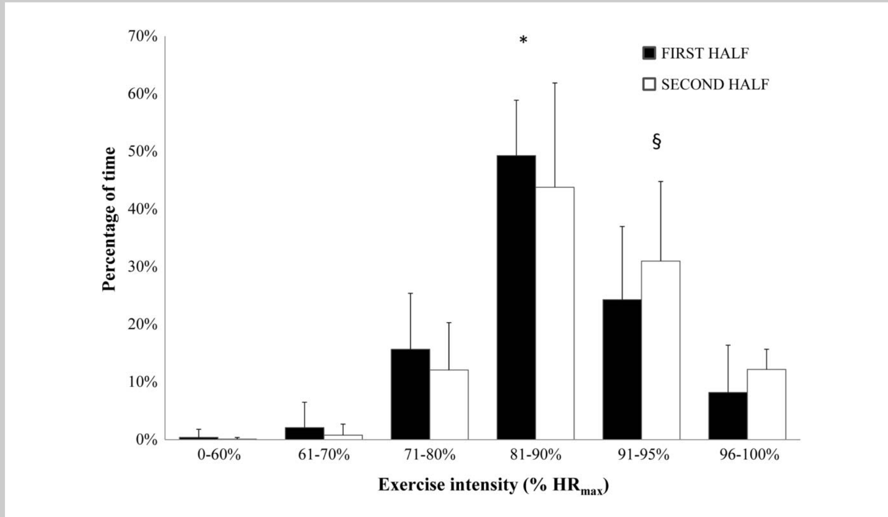

Figure 2. Percentage of playing time spent at each exercise intensity zone during each half in men Rugby 7s players ($n = 17$). *Significantly higher than any other exercise intensity zone ($p < 0.05$). §Significantly differences between halves ($p < 0.05$). Data are mean ± *SD*.

of a "gold standard" method, the current system has been reported to be capable of measuring individual movement patterns in other team sports (16).

Match Running Demands Analysis

Time-motion data of all the players who participated in the entire first and second halves were retained ($n = 17$ files from 7 different players). After collection, all match data were analyzed with the software provided by the manufacturer (Team AMS; GPSports, V1.2) designed to provide objective measures of physical match performance. Players' activities were coded into the following categories and speed thresholds: standing and walking (0–6.0 $km \cdot h^{-1}$), jogging (6.1–12.0 $km \cdot h^{-1}$), cruising (12.1–14.0 $km \cdot h^{-1}$), striding (14.1–18.0 $km \cdot h^{-1}$), high-intensity running (18.1–20.0 $km \cdot h^{-1}$), and sprinting (>20.1 $km \cdot h^{-1}$). The speed thresholds for each category were the same to those reported previously by Cunniffe et al. (4) using the GPS technology. Similar to Cunniffe et al. (4), the above categories were divided into further locomotor categories to provide an estimation of player work-to-rest ratios: (a) low-intensity activity (0–6.0 $km \cdot h^{-1}$) and (b) moderate-and-high-intensity activity (>6.1 $km \cdot h^{-1}$). The frequency of high-speed zone entries (sprints >20 $km \cdot h^{-1}$) and the highest speed recorded during the game were also collected. Average speed (kilometers per hour) was also calculated from the total distance covered in each half divided by the time spent on the ground for each individual player.

Exercise Intensity

Match exercise intensity was quantified by monitoring the HR during each match. The HR was continuously measured (every 1 second) with short-range telemetry (SPI Elite, GPSports) and was expressed in relation to the individual HRmax reached during the incremental treadmill test. In those players in whom HRs were higher in the course of the match than the determined value during the incremental treadmill test, the HRmax values obtained during the game were retained and used in the analysis. The HR data were classified based on percentage of total playing time spend in each of the following 6 HR zones: zone 1 (<60% HRmax), zone 2 (61–70% HRmax), zone 3 (71–80% HRmax), zone 4 (81–90% HRmax), zone 5 (91–95% HRmax), and zone 6 (>96% HRmax).

Statistical Analyses

Data are presented as mean ± *SD*. Differences between the first and second halves were determined using Student's dependent *t*-test. Differences between distance covered at different running intensities and time spent at different HR intensities were analyzed using a 1-way analysis of variance with repeated measures. When a main effect was found, Bonferroni's adjusted post hoc tests were applied. All analyses were carried out with SPSS 17.0 (SPSS Inc, Chicago, IL, USA) software with the level of significance set at $p \leq 0.05$.

Results

Match Running Demands

Mean total distance (±*SD*) covered over the whole match by all the players was 1,580.8 ± 146.3 m, ranging from 1,348.8–1,975.7 m. Figure 1 shows the match running profile during each half. There were no significant differences in match running performance between the 2 halves. The players spent longer standing, walking and jogging (i.e., running speeds between 0 and 12 $km \cdot h^{-1}$) than at any other running speed ($p < 0.05$). Low-intensity activities represented 61% of total time, which consisted of 34.8% (549.7 ± 79.1 m) standing and walking and 26.2% (414.8 ± 105.1 m) jogging. Cruising, striding, high-intensity running, and sprinting represented 9.8% (154.6 ± 53.5 m), 15.5% (244.5 ± 80.1 m), 5% (79.5 ± 37.2 m), and 8.7% (137.7 ± 84.9 m) of total time, respectively. The player's work-to-rest ratio was 1:0.5 (i.e., for every 1 minute of work, there was 0.5 minutes of rest). The average speed obtained throughout the game was 6.4 ± 0.6 $km \cdot h^{-1}$, with no significant differences between the first and second halves (6.4 ± 0.6 and 6.4 ± 0.6 $km \cdot h^{-1}$, respectively).

Table 1 displays sprinting performance results obtained during matches. Maximum speed obtained by a player during a match corresponded to 29.9 $km \cdot h^{-1}$, and the longer sprint record (>20 $km \cdot h^{-1}$) was of 67.1 m.

Exercise Intensity

The average HR in the first and second halves was 169 ± 4 (86.6 ± 2.0% HRmax) and 173 ± 6 (88.6 ± 3.0% HRmax), respectively, with no significant differences observed. Maximal HR was 193 ± 5 (98.9 ± 2.0% HRmax) in the first half and 194 ± 5 (99.3 ± 2.0% HRmax) in the second half with no differences observed. Figure 2 shows the percentage of playing time spent in each exercise intensity zone expressed as percentage of HRmax. The players spent most of their playing time at HR intensities between 81 and 90% HRmax, with significant differences observed between halves in zone 5.

Discussion

The aim of this study was to analyze for the first time the match running demands and exercise intensity associated with high-level men rugby 7s using an objective method like GPS technology. The only peer-reviewed study on the activity profile of male rugby 7 during competitive matches used notational analysis based on qualitative data and objective running performance (e.g., distance covered) was not provided (17); therefore, comparison of our results is not possible. The results of this study show that, during a rugby 7s match, a man rugby player covers 1,580.8 ± 146.3 m at various speeds, resulting in an average running speed of 6.4 $km \cdot h^{-1}$. With the same technology used in this study (i.e., GPS), it was found that male rugby union (15-a side) players covered a total match distance of 6,953 m and exercised at an average running speed of approximately 4.2 $km \cdot h^{-1}$ (4). Male rugby league (13-a side) players covered a total match distance of 4,982 m (forwards) and 5,573 m (backs) in a whole game (13). Using different technologies (i.e., video analysis), previous studies have reported that elite, male rugby union players covered average distances ranging from 4,662 to 6,389 m (1,7,11,18). Extrapolating the men rugby 7s playing time to the 15-a side male rugby match duration (~80 minutes) (4), the resulting figure is a game coverage of approximately 9,000 m. Thus, as expected, overall running demands appear to be much higher in rugby 7s than in the a-15 rugby code.

The players studied in the present investigation spent 13.7% of the time in high-intensity running activities (18–20 $km \cdot h^{-1}$) or sprint (>20.1 $km \cdot h^{-1}$), which was slightly higher than the 10.5% previously reported in male rugby union players (4), and the 6.5% reported in rugby league players (13) (4.7% forwards vs. 8.3% backs). The average number of sprints (>20.1 $km \cdot h^{-1}$) reported in this study was approximately 7 per match (Table 1). On average, these sprints corresponded to an average distance of approximately 18 m, which falls within the range to those previously reported in different rugby codes with male players (1,4–6). Present data also reveal that rugby 7s players are required to sprint over distances >40 m. This implies that specific sprint training should reflect these demands and both short (≤20 m) and longer sprints (40–50 m) have to be included in the speed training routines.

The work-to-rest ratio values reported in this study (1:0.5) are substantially lower than any of those previously reported in other rugby union codes (ranging from 1:4 to 1:2) (1,4,7,11,13,14). Although comparisons with previous studies are difficult because analysis systems and criteria to classify motion categories have differed across studies, the present results suggest that stoppages in play are shorter and less frequent in rugby 7s than in the 15-aside code (11). The substantially reduced time spent in low-running speed activities identified in this study, together with the similar scores observed in rugby 7s compared with the other rugby codes, suggests a quicker transition of the ball from attack to defense phases and vice versa. This supports the notion that rugby 7s is played at much faster running tempo than the other rugby codes.

Despite the intensified running activity observed in this study, the average percentage of the total playing time that players spent at HR intensities >90% HRmax (i.e., 37.8%) was lower than those previously reported in male, rugby union players; backs and forwards spent 41.4 and 51.1% of the total time at HR intensities >90% of HRmax, respectively (4). Thus, the elevated running demands in rugby 7s do not appear to be associated with an increased overall exercise intensity (i.e., exemplified via HR responses). It can be speculated that the higher number or frequency of other game-related, nonlocomotive activities such as pushing and pulling in rucks or scrums observed in the other rugby codes can account, at least partially, for these differences in HR responses. These nonlocomotive activities are registered as low-running speed activities despite the high-intense nature of those actions (4). Further studies that combine objective GPS data with qualitative analysis of time spent in nonrunning activities are required to elicit more specific demands of the rugby 7s game.

This study is the first to show that rugby 7s is characterized by relatively high running demands intercalated with short periods of recovery. This study also suggests that the physical demands of rugby 7s are quite different from those encountered in other rugby codes. Collectively, these finding provide important information for prescription of training aimed at developing physiological qualities specific to the demands of competitive men rugby 7s.

Practical Applications

The assessment of the external (i.e., running demands) and internal (i.e., HR responses) load imposed during the actual competition is the first step preceding the design of specific conditioning programs and physical fitness testing protocols in rugby 7s. The training regimes of strength and conditioning coaches need to meet the increased overall running demands, the augmented high-intensity running actions, and the reduced work-to-rest ratios observed in rugby 7s in comparison with other rugby codes. As such, the development of appropriate levels of intermittent aerobic fitness is recommended.

Acknowledgments

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