

**The validity of the BioForce Heart Rate  
Variability System and the use of heart rate  
variability and recovery to determine the  
fitness levels of a cohort of university-level  
rugby players**

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## LIST OF ABBREVIATIONS

ANS	Autonomic nervous system
CHO	Carbohydrates
CSAI-2	Competitive State Anxiety Inventory-2
ECG	Electrocardiograph
FOR	Functional over reaching
HF	High frequency power
HF%	High frequency power expressed as percentage
HFnu	High frequency normalized power
HRmax	Maximal heart rate
HRR	Heart rate recovery
HRV	Heart rate variability
LF	Low frequency power
LF%	Low frequency power expressed as percentage
LF%: HF%	Low and High frequency power percentage expressed as a ratio
LF:HF ratio	Low and High frequency expressed as a ratio
LFnu	Low frequency normalised power
Ln-RMSSD	Logarithm applied for RMSSD
MAS	Maximal aerobic speed
NFOR	Non-functional over reaching
PNS	Parasympathetic nervous system
RCP	Respiratory compensation point
RER	Respiratory exchange ratio
RMSSD	Squared root of the mean squared differences between successive R-R intervals
R-R intervals	Inter-beat intervals or R to R intervals
SD1	Standard descriptor 1

SD2	Standard descriptor two
SDNN	Standard deviation of R-R intervals
SNS	Sympathetic nervous system
TP	Total power
$\dot{V}O_{2\max}$	Maximal oxygen uptake
$\dot{V}O_{2\text{peak}}$	Peak oxygen uptake
$\dot{V}O_2$	Oxygen consumption
$\dot{V}CO_2$	Ventilatory carbon dioxide production
$\dot{V}_E/\dot{V}O_2$	Minute ventilation over oxygen consumption
$\dot{V}_E/\dot{V}CO_2$	Minute ventilation over carbon dioxide production
$\dot{V}_E$	Minute ventilation
VT1	Ventilatory threshold one
VT2	Ventilatory threshold two
Yo-Yo IR1	Yo-Yo Intermittent Recovery Test One

# SUMMARY

The potential to track changes in training status and fitness levels of especially team sport participants by making use of more time efficient and accessible methods such as heart rate variability (HRV) and heart rate recovery (HRR) cannot be overlooked and needs to be considered. However, studies that have investigated this aspect in team sport participants are scarce. It is against this background that the main objectives of this study were firstly, to determine the relationships between HRV and HRR as well as the fitness levels of a cohort of university-level rugby players. The second objective was to determine the validity of the BioForce Heart Rate Variability System to determine the HRV of a cohort of university-level rugby players.

Twenty-four university-level rugby players (age:  $20.1 \pm 0.41$  years; body stature:  $182.7 \pm 6.2$  cm; body mass:  $89.7 \pm 12.7$  kg) of a South African university's Rugby Institute participated in the first part of the study. During the test day players' fasting baseline HRV (baseline HRV) values were taken. This was followed by the measurement of the post-breakfast HRV (Pre-Yo-Yo IR1 HRV). Players were then required to perform the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1) while they were fitted with a portable Cosmed K4b<sup>2</sup> gas analyser apparatus and a Fix Polar Heart Rate Transmitter Belt. After completion of the test, HRR was taken on 1 and 3 minutes and followed by the measurement of HRV (Post-Yo-Yo IR1 HRV). For the second part of the study a group of twenty u/21 university-level rugby players (age:  $20.06 \pm 0.40$  years; body stature:  $181.8 \pm 5.5$  cm; body mass:  $91.1 \pm 10.7$  kg) of a South African university's Rugby Institute were recruited to participate in this study. HRV was measured simultaneously by the Actiheart monitor system as well as the BioForce Heart Rate Variability System over three times periods: during the morning in a fasting state just after players had woken up (baseline); in the morning just after the players ate breakfast (pre-anaerobic); after completion of a high-intensity anaerobic training session (post-anaerobic) and after completion of a 20 min recovery session (post-recovery).

Significant correlations ( $p \leq 0.05$ ) were found between Pre-Yo-Yo IR1 HRV and heart rate (HR) at the respiratory compensation point (RCP-HR (bpm)) ( $r = -0.468$ ) as well as oxygen uptake at the RCP ( $\text{RCP-}\dot{V}O_{2\text{max}}$  (% of  $\dot{V}O_{2\text{max}}$ )) ( $r = 0.476$ ), respectively. A forward stepwise regression analysis showed that HR at ventilatory threshold 1 (VT1-HR (bpm)) contributed

significantly ( $p \leq 0.05$ ) to the post-Yo-Yo IR1 HRV with a variance of 39.8%. Final Yo-Yo IR1 level also contributed significantly ( $p \leq 0.05$ ) to 3 minute post-Yo-Yo IR1 HRR with a variance of 16.5%.

For the second part of the study the majority of significant relationships ( $p < 0.05$ ) between the Actiheart and Bioforce obtained HRV results were observed for the post-recovery period (Mean RR, SDNN, RMSSD and Peak LF power), followed by the pre-anaerobic period (Mean R-R and SDNN) and the baseline period (LF:HF ratio). No significant relationships were observed between the HRV results of the two apparatuses during the post-anaerobic period.

In conclusion, HRV and HRR may have the potential to act as affordable and easy measurement tools of team sport participants' fitness levels. However, the study results suggested that the BioForce Heart Rate Variability System that is used to obtain team sport participants' HRV is especially valid to determine HRV after recovery periods that follow hard training sessions. The results do however cast a shadow of doubt over the accuracy of this apparatus when used directly after hard training sessions.

**Keywords:** BioForce Heart Rate Variability System; Heart rate variability; Rugby players; Yo-Yo Intermittent Recovery Test Level 1; Autonomic nervous system

# OPSOMMING

Die potensiaal om veranderinge in oefeningstatus en fiksheidvlakke van veral spansportdeelnemers te monitor deur gebruik te maak van meer tyds-effektiewe en toeganklike metodes soos harttempo-varieerbaarheid (HTV) en harttempoherstel (HTH) kan nie misgekyk word nie en moet oorweeg word. Studies wat egter hierdie aspek in spansport-deelnemers ondersoek het, is skaars. Dit is teen hierdie agtergrond dat die primêre doelwitte van dié studie ten eerste was om die verbande tussen HTV en HTH sowel as die fiksheidvlakke van 'n groep universiteitsvlak rugbyspelers vas te stel. Die tweede doelwit was om die geldigheid van die BioForce Heart Rate Variability System om die HTV van 'n groep universiteitsvlak rugbyspelers te bepaal, vas te stel.

Vier-en-twintig universiteitsvlak rugbyspelers (ouderdom:  $20.1 \pm 0.41$  jaar; liggaamslengte:  $182.7 \pm 6.2$  cm; liggaamsmassa:  $89.7 \pm 12.7$  kg) van 'n Suid-Afrikaanse universiteit se Rugby-instituut het aan die eerste deel van die studie deelgeneem. Gedurende die toetsdae is spelers se basislyn-HTV waardes (basislyn HTV) bepaal. Dit is opgevolg met die meting van die post-ontbyt HTV (Pre-Yo-Yo IR1 HTV). Hierna is daar van spelers verwag om die Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1) uit te voer terwyl hulle die draagbare Cosmed K4b2 gasontleider-apparaat en 'n Polar Heart Rate Transmitter Belt gedra het. Na afloop van dié toets, is HTH geneem op 1 en 3 minute en gevolg deur die meting van HTV (Post-Yo-Yo IR1 HTV). Vir die tweede deel van die studie is 'n groep van twintig o/21 universiteitsvlak rugbyspelers (ouderdom:  $20.06 \pm 0.40$  jaar, liggaamslengte:  $181.8 \pm 5.5$  cm; liggaamsmassa:  $91.1 \pm 10.7$  kg) van 'n Suid-Afrikaanse universiteit se Rugby-instituut gewerf om deel te neem aan dié studie. HTV is tegelyktyd gemeet deur die Actiheart monitorsisteam, sowel as die BioForce Heart Rate Variability System oor drie periodes: tydens die oggend in 'n vastende toestand net na spelers wakker geword het (basislyn); in die oggend net na die spelers ontbyt geëet het (pre-anaërobies); na voltooiing van 'n hoë-intensiteit anaërobiese oefeningsessie (post-anaërobies) en na voltooiing van 'n 20-min herstelsessie (post-herstel).

Betekenisvolle korrelasies ( $p \leq 0.05$ ) is gevind tussen Pre-Yo-Yo IR1 HTV en harttempo (HT) by die respiratoriese kompensasiënpunt (RCP-HT (slae/min)) ( $r = -0.468$ ) sowel as vir suurstofopname by die RKP ( $RKP \cdot \dot{V}O_{2maks}$  (% van  $\dot{V}O_{2maks}$ )) ( $r = 0.476$ ). 'n Voorwaartse, stapsgewyse regressie-analise het getoon dat HT by die ventilatoriese drempelpunt 1 (VD1-HT

(slae/min)) betekenisvol bygedra ( $p \leq 0.05$ ) het tot post-Yo-Yo IR1 HTV met 'n variansie van 39.8 %. Finale Yo-Yo IR1 vlak het ook betekenisvol bygedra ( $p \leq 0.05$ ) tot die 3 minute post-Yo-Yo IR1 HTH met 'n variansie van 16.5%. Vir die tweede deel van die studie is die meerderheid van betekenisvolle verbande ( $p \leq 0.05$ ) tussen die Actiheart en Bioforce verkrygte HTV resultate waargeneem vir die post-herstel periode (Gemiddelde RR, SDNN, RMSSD en Piek LF krag), gevolg deur die pre-anaërobiese periode (Gemiddelde RR en SDNN) en die basislyn periode (LF:HF ratio). Geen betekenisvolle verbande is gevind tussen die HTV resultate van die twee apparate tydens die post- anaërobiese tydperk nie.

Ten slotte, HTV en HTH mag die potensiaal toon om as bekostigbare en maklike meetinstrumente van spansportdeelnemers se fiksheidvlakke te dien. Die studieresultate het egter daarop gedui dat die BioForce Heart Rate Variability System wat gebruik word om spansportdeelnemers se HTV te verkry, veral geldig is om HTV te bepaal na herstelperiodes wat volg op harde oefeningsessies. Die uitslae werp egter 'n skaduwee van twyfel oor die akkuraatheid van hierdie apparaat vir gebruik direk na harde oefensessies.

**Sleutelterme:** BioForce Heart Rate Variability System; Harttempo-varieerbaarheid; Rugbyspelers; Yo-Yo Intermittent Recovery Test Level 1; Outonome senuweesisteem

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## DECLARATION

The co-authors of the two articles, which form part of this dissertation, Ben Coetzee (Supervisor), Cindy Pienaar (Co-Supervisor), hereby give permission to the candidate, Christo Bisschoff to include the two articles as part of a Master's dissertation. The contribution (advisory and supportive) of the co-authors kept within reasonable limits, thereby enabling the candidate to submit this dissertation for examination purposes. This dissertation, therefore, serves as fulfillment of the requirements for the degree Master of Science degree in Sport Science within Physical Activity, Sport and Recreation in the Faculty of Health Sciences at the North-West University (Potchefstroom Campus).

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# CHAPTER 1

## INTRODUCTION



## 1.1 PROBLEM STATEMENT

The clinical use of heart rate variability (HRV) to evaluate health status in the general population, has led exercise physiologists and coaches to investigate the use, applicability and suitability of this parameter to analyse and evaluate different aspects in the physiological make-up of sport participants (Chen *et al.*, 2011:1546; Gamelin *et al.*, 2006:887). HRV can be defined as the amount of heart rate fluctuation in the mean heart rate and can be quantified by the analysis of the successive cardiac cycles of a person (Pumprla *et al.*, 2002:3). HRV reflects the modulation of cardiac function by the autonomic nervous system (ANS) and other physiological regulatory systems (Acharya *et al.*, 2006:1031). Another technique that is used to measure the responsiveness of the ANS is the measurement of heart rate recovery (HRR) (Lamberts *et al.*, 2009:711; Buchheit *et al.*, 2007:H8). According to Aubert *et al.* (2003:900), the cardiovascular system is constantly regulated by autonomic activity to ensure optimal efficiency of cardiac functions, and HRV as well as HRR may be useful tools to examine autonomic fluctuations under different physiological conditions such as training. Therefore, the potential to track changes in training status and fitness levels of especially team sport participants by making use of more time efficient and accessible methods such as HRV and HRR (Gamelin *et al.*, 2006:887), cannot be overlooked and needs to be considered.

Cardiorespiratory endurance or maximal aerobic power is one of the main indicators of physical fitness (Hansen *et al.*, 2012:2.; Porro *et al.*, 2011:682; Welk *et al.*, 2011:111) and is determined by the direct measurement of  $\dot{V}O_2$  by indirect calorimetry and specifically by open-circuit spirometry during a graded maximal test in the laboratory (O’Gorman *et al.*, 2000:62). This is the most accurate way of assessing the aerobic capacity or maximal aerobic power of athletes (O’Gorman *et al.*, 2000:62). Previous studies have demonstrated that  $\dot{V}O_{2max}$  (maximal oxygen uptake) and submaximal, physiological parameters such as ventilatory threshold one (VT1) and the respiratory compensation point (RCP), that can all be obtained from the graded maximal test and spirometry analysis, are very good indicators of maximal aerobic power or endurance performance (Amann *et al.*, 2004:620; Edwards *et al.*, 2003:23; Svedahl & Macintosh, 2003:301). However, the direct measurement of physical fitness (maximal aerobic power) requires the use of specialised, sophisticated equipment which is very expensive, needs well-trained personnel to operate (Cooper *et al.*, 2005:1; O’Gorman *et al.*, 2000:62) and is time consuming and therefore impractical for measuring large groups of athletes (Gunjo *et al.*, 2011:87; Lee *et al.*, 2011:2573; Zhu *et al.*, 2010:400). These and other constraints have

compelled researchers to consider the suitability and accuracy of HRV and HRR to determine the physical fitness levels of athletes as well as possible changes that may occur with regard to this component (Gamelin *et al.*, 2006:887).

Most HRV studies make use of a spectral analysis as recording method to produce a power spectrum as outcome (Acharya *et al.*, 2006:1037; Aubert *et al.*, 2003:896). Over time, researchers have discovered that the high frequency components (HF) of the HRV signal are mediated by the parasympathetic nervous system, whereas low frequency components (LF) are mediated by the sympathetic nervous system (Martinmaki *et al.*, 2008:546; Lewis *et al.*, 2007:35; Hedelin *et al.*, 2001:1397). As a result the ratio between HF and LF can be used to quantify and provide an accurate index of the sympathovagal balance (Lewis *et al.*, 2007:35; Lopes & White, 2006:41). In this regard Aubert *et al.* (2003:901) and Lewis *et al.* (2007:35) found that the LF:HF ratio increased during low intensity exercise which may be an indication of a withdrawal of the parasympathetic stimuli, while simultaneously, an enhancement of sympathetic stimuli is initiated. Furthermore, De Meersman (1993:726) reported significantly higher HRV values (as indicated by the absolute HF and LF values) for aerobically conditioned and fit persons compared to aerobically unconditioned and unfit persons. Similarly, Achten and Jeukendrup, (2003:523) found consistently higher HRV in endurance trained athletes when compared to untrained individuals and suggested that vigorous training is required to induce changes in HRV. Contradictory to the last-mentioned research results, a number of studies (Martinmaki *et al.*, 2008:544; Bosquet *et al.*, 2007:367) revealed no change in HRV or ANS activity during high intensity exercise in long and middle-distance runners as well as sedentary volunteers, nor found any significant correlation between  $\dot{V}O_{2\max}$  and the HRV results. Some of the last-mentioned researchers did, however, allude to the fact that these conclusions should be interpreted with caution due to the relatively small sample size and widely distributed HRV data of studies (Hedelin *et al.*, 2001:1397).

Only a few researchers have investigated the HRV indices of team sport participants. For example, Ke-tien *et al.* (2012) investigated the influence of an eight week long cardio-respiratory endurance training program on HRV and  $\dot{V}O_{2\max}$  of 24 male rugby players. They observed that the cardio-respiratory endurance training program led to significant increases ( $p < 0.05$ ) in HF and LF:HF ratio (Ke-tien *et al.*, 2012:1224). Another study revealed that SDNN (standard deviation of R-R intervals and a reflection of global variability) and SD2 (standard descriptor 2 and a representation of long term variability) correlated significantly with Yo-Yo IR1

performance ( $r = 0.89$ ,  $p = 0.07$  and  $r = 0.92$ ,  $p = 0.03$ ) in male elite soccer players after an eight week pre-season training period (Boullosa *et al.*, 2013:403). All of these last-mentioned studies therefore suggest that HRV can possibly serve as an indicator of training status and fitness level changes in team sport participants.

HRR is another parameter that is dependent on the balance between parasympathetic and sympathetic nervous system activity (Borresen & Lambert, 2008:640). After cessation of maximal exercise the ability of the parasympathetic nervous system to slow down the heart rate after sympathetic nervous system and subsequent heart rate stimulation, is an indication of an individual's fitness level (Borresen & Lambert, 2008:641; Kannankeril *et al.*, 2004:394). In this regard it has been established that well trained endurance athletes exhibit a faster than normal HRR after maximal exhaustive exercise compared to sedentary control groups (Seiler *et al.*, 2007:1372; Lucia *et al.*, 2000:1781). Esco *et al.* (2011:2304) also concluded that a more efficient HRR will contribute to higher HRV readings. Changes in HRR and HRV indices have also been associated with improvements in neuromuscular-related performance parameters such as repeated sprint ability in handball players (Buchheit *et al.*, 2008:368). Due to the fact that rugby requires a complex combination of both cardio respiratory and neuromuscular fitness, the potential of HRR and HRV to predict changes in both aerobic fitness and neuromuscular performance should be noted (Buchheit *et al.*, 2012:712).

The use of an electrocardiograph (ECG) is the favoured and most accurate method to measure HRV (Lopes & White, 2006:41). However, the complexity and cost of high quality ECG equipment has made it difficult to assess HRV during and after on-field training conditions (Gamelin *et al.*, 2006:887). In view of these shortcomings with regard to the use of ECG to determine HRV, the manufacturers of heart rate monitors have developed more affordable wireless heart rate monitors that can be used to determine the HRV of sport participants. In this regard a study by Gamelin *et al.* (2006:887) revealed that the Polar heart rate monitor (Polar S810) delivered HRV results that were not significantly different from the HRV results that were obtained from ECG, and concluded that the Polar heart rate monitor was a valid instrument for determining the HRV of sport participants. In contrast, Nunan *et al.* (2009:243) demonstrated that the Polar heart rate monitors are not adequate to detect small and precise changes in HRV readings, but concluded that these monitors can be successfully used to make comparisons between different subjects.

However, despite the fact that the Polar heart rate monitors provide a more affordable way to measure HRV, the user must still make use of complex calculations and different software to obtain the HRV values. At the end of 2011 a new apparatus, namely the BioForce Heart Rate Variability System (Performance Sport Inc., Washington, USA) emerged on the market. According to the manufacturers the system has the ability to measure and provide the HRV values of a sport participant in 3 minutes by making use of a Polar heart rate transmitter belt. According to the developer's website, the HRV values that were obtained from this system correlated well with the Omegawave Sport Technology System (Omegawave, Portland, Oregon, USA) (Jamieson, 2011). Due to the fact that Berkoff *et al.* (2007:228) alluded to the fact that the Omegawave device complies with all guidelines recommended by the task force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology Standards for Measurement of HRV, this device can be regarded as a valid apparatus to measure HRV. However, no studies could be located that have investigated the validity of the BioForce System to measure the HRV of team sport participants.

Therefore, despite the potential of HRV and HRR to act as indicators of team sport participants' fitness levels and the emergence of a more affordable and user-friendly apparatus (BioForce Heart Rate Variability System) by which these measurements can be obtained, studies that have investigated this aspect in team sports participants are scarce. It is against this background, that the following research questions are posed: Firstly, what are the relationships between HRV and HRR as well as the fitness levels of a cohort of university-level rugby players? Secondly, what is the validity of the BioForce Heart Rate Variability System to determine the HRV of a cohort of university-level rugby players? Answers to these questions will possibly provide coaching staff and other sport related professionals with information regarding the accurateness and usefulness of HRV and HRR as indicators of fitness level in a cohort of university-level rugby players. It may also give people in the sporting fraternity an indication of the validity and usefulness of the BioForce Heart Rate Variability System to determine the HRV of team sport participants.

## **1.2 OBJECTIVES**

The main objectives of this study are to determine:

- The relationships between HRV and HRR as well as the fitness levels of a cohort of university-level rugby players.
- The validity of the BioForce Heart Rate Variability System to determine the HRV of a cohort of university-level rugby players.

### 1.3 HYPOTHESES

The following hypotheses are formulated for this study:

- Significant positive relationships will exist between HRV and HRR as well as the fitness levels of a cohort of university-level rugby players.
- The BioForce Heart Rate Variability System is a valid system to determine the HRV of a cohort of university-level rugby players.

### 1.4 STRUCTURE OF DISSERTATION

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

**Chapter 1:** Introduction. A bibliography will be provided at the end of the chapter in accordance with the guidelines of the North-West University.

**Chapter 2:** Literature overview: The influence of exercise and fitness levels on heart rate variability and recovery. A bibliography will be provided at the end of this chapter in accordance with the guidelines of the North-West University.

**Chapter 3:** Article 1 – The relationship between heart rate variability and recovery as well as the fitness levels of a cohort of university-level rugby players. This article will be submitted to the *Journal of Strength and Conditioning Research*. This chapter and the bibliography that will be presented at the end of this chapter will be compiled in accordance with the guidelines of the journal. Although not according to the guidelines of the journal, tables will be included within the text as so to make the article easier to read and understand. Furthermore, the line spacing of the article will be set as 1.5 lines.

**Chapter 4:** Article 2 – The validity of the BioForce Heart Rate Variability System to determine the heart rate variability of a cohort of university-level rugby players. This article will be submitted to the *European Journal of Sport Science*. This chapter and the bibliography that will be presented at the end of this chapter will be compiled in accordance with the guidelines of the journal. Although not according to the guidelines of the journal, tables will be included within the text as so to make the article easier to read and understand. Furthermore, the line spacing of the article will be set as 1.5

lines.

- Chapter 5:** Summary, conclusions, limitations and recommendations
- Appendix A:** The demographic, general information questionnaire and informed consent forms
- Appendix B:** Data collection forms
- Appendix C:** The instructions for authors from the *Journal of Strength and Conditioning Research* as well as an example of an article that was published in the journal.
- Appendix D:** The instructions for authors from the *European Journal of Sport Science*, as well as an example of an article that was published in the journal.
- Appendix E:** Proof of professional language editing

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## CHAPTER 2

### **LITERATURE OVERVIEW: THE INFLUENCE OF EXERCISE AND FITNESS LEVELS ON HEART RATE VARIABILITY AND RECOVERY**



## 2.1 INTRODUCTION

Heart rate variability (HRV) has become a promising method to monitor adaptation to physical training and involves the regular monitoring of the cardiac autonomic nervous system (ANS) status (Plews *et al.*, 2013:773). HRV can be defined as a measure of the beat-to-beat variation and the time duration between each completed cardiac cycle (heart beat) (Armstrong *et al.*, 2012:501; Karapetian *et al.*, 2008:652). Heart rate recovery (HRR), which is the rate at which heart rate decreases (or time taken for heart rate to recover) after moderate to heavy exercise (Borresen & Lambert, 2008:640), is also a well established measure of cardiac ANS function and is commonly used in tandem with HRV (Lamberts *et al.*, 2009:706). While it is well-known that well-trained subjects exhibit a faster HRR (associated with aerobic fitness) compared to untrained subjects, the use of HRV indices to monitor the training status of athletes has also in recent times received more attention by coaches and sport scientists (Makivic *et al.*, 2013:110; Plews *et al.*, 2013:774; Lamberts *et al.*, 2009:706). Despite the potential of HRV and HRR to act as indicators of athletes' fitness levels and the emergence of a more affordable and user-friendly apparatus by which these measurements can be obtained, studies that have investigated these aspects in athletes are scarce and contradictory (Sartor *et al.*, 2013:2783; Jamieson, 2011).

It is against this background that the following literature review was compiled. The primary aim of this chapter was to provide a review of HRV and HRR as indices to monitor ANS function in exercise and sport settings. In order to fulfil the last-mentioned aim, the following steps were followed in compiling the review: Firstly, the physiology of the ANS was explained in order to provide the reader with a better understanding of the use of HRV and HRR as tools to examine autonomic fluctuations under different physiological conditions. Secondly, methodological aspects of HRV and HRR measurements were discussed and explained. Thirdly, the value of using HRV and HRR in sport and exercise settings was discussed. Finally, limitations of using these parameters in sport and exercise were explained by making use of the available literature. The literature review only targeted literature which focussed on HRV and HRR as the primary variables of investigation and that used athletes and especially team sport participants as study subjects. Studies that looked at the use of HRV and HRR in a clinical setting were excluded from this review. Furthermore only studies that were published after 2000 and especially after 2010 were selected for use in this review. However, in some cases older literature were cited to give background concerning the use of HRV and HRR; to provide information with regard to the advantages and disadvantages of using HRV and HRR and lastly to discuss certain

methodological aspects that need to be considered when using these parameters of ANS function.

## **2.2 THE PHYSIOLOGY OF THE AUTONOMIC NERVOUS SYSTEM**

The ANS can be described as the portion of the nervous system which controls most of the visceral functions of the body (Shier *et al.*, 2007:427). Visceral functions such as arterial pressure, sweating, body temperature, gastrointestinal motility, gastrointestinal secretion, bladder emptying and many other physiological functions (Table 2.1), are some of the functions which are entirely or partially controlled by the ANS (Guyton & Hall, 2006:748). The ANS also forms an integral part of the properly functioning human body due to the rapidity and intensity with which it can alter physiologic processes (Lee, 2001:40). As a result of the pivotal role that the ANS plays in regulating bodily functions, healthcare professionals have extensively studied this part of human physiology in order to assess the usefulness of ANS related indices in evaluating various aspects such as cardiac mortality, neurological disorders, renal failure, diabetes, fitness and sport performance (Acharya *et al.*, 2006:1034; Aubert *et al.*, 2003:891). The ANS originates in the spinal cord, brainstem and hypothalamus which receives and is stimulated by visceral reflexes *via* subconscious sensory signals (Shier *et al.*, 2007:427; Guyton & Hall, 2006:748) from various visceral organs, which in turn transmits a subconscious reflex response directly back to the visceral organ to regulate its activities (Rhoades & Bell, 2013:108; Widmaeir *et al.*, 2006:200).

The ANS is divided into two major subdivisions namely the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS) which have antagonistic characteristics but function synergistically with great efficiency (Wilmore *et al.*, 2008:91). Virtually all of the neurons in the SNS secrete the neurotransmitter norepinephrine, which is why researchers consider norepinephrine to be a sympathetic neurotransmitter (Shier *et al.*, 2007:432; Lee, 2001:43). On the other hand acetylcholine is considered to be a parasympathetic neurotransmitter in view that almost all of the neurons in the PNS secrete this neurotransmitter (Makivic *et al.*, 2013:106; Rhoades & Bell, 2013:109).

The SNS is also called the “fight or flight system” as a result of its capability to prepare and sustain the body to face a crisis or danger (Guyton & Hall, 2006:747). A massive sympathetic discharge during such an event triggers a series of physiological adaptations (Table 2.1) to cope with the current situation (Wilmore *et al.*, 2008:90). During exercise and competition

participation the body is predominantly stimulated by sympathetic nerves to better cope with the stresses of exertion (Aubert *et al.*, 2003:900).

The PNS's effects oppose those of the SNS (Wilmore *et al.*, 2008:90). The PNS is often referred to as the body's "house-keeping system" for its major role in regulating important processes such as digestion, urination, glandular secretion and the conservation of energy (Aubert *et al.*, 2003:891). The PNS is more active when a person is calm and relaxed and little physical demand is put on the body (Wilmore *et al.*, 2008:90). During sleep and normal situations the body is predominantly stimulated by parasympathetic nerves to either recover from a previous exertion or to maintain normal bodily functions (Aubert *et al.*, 2003:911; Acharya *et al.*, 2006:1036).

The PNS and SNS exhibit an antagonistic relationship in the regulation of bodily functions (Shier *et al.*, 2007:427). The end result of this antagonistic relationship is a very effective and responsive regulation of the cardiovascular system as well as other systems such as the digestive system, ocular mechanisms of the eyes and glycogen production in the liver (Guyton & Hall, 2006:748). Table 2.1 shows the organs/systems and bodily functions that are primarily targeted by the SNS and PNS.

From Table 2.1 it is clear that the ANS needs to function efficiently at all times to maintain a state of homeostasis (Rhoades & Bell, 2013:108; Lee, 2001:44). In view of the importance of the ANS for the body to function normally it is imperative to frequently assess the ANS in order to determine if it is functioning properly (Sztajzel, 2004:514). Therefore, in view of the fact that the ANS is a critical part of the body's physiological functions, it would be of the utmost importance to assess the status of the ANS regularly.

**Table 2.1: A summary of the ANS's effects on vital bodily functions (Rhoades & Bell, 2013:115; Wilmore *et al.*, 2008:90; Shier *et al.*, 2007:434; Guyton & Hall, 2006:748; Widmaeir *et al.*, 2006:200; Aubert *et al.*, 2003:911)**

<b>Targeted organ/ system and bodily function</b>	<b>SNS effects on system</b>	<b>PNS effects on system</b>
Heart muscle	Increases the rate and the force of contraction	Decreases the rate and the force of contraction
Coronary blood vessels	Causes vasodilatation	Causes constriction
Lungs	Causes bronchodilation	Causes bronchoconstriction
Blood vessels	Causes vasoconstriction in the abdominal viscera and skin as well as vasodilatation in the skeletal muscles and heart during exercise	Little effect
Liver	Stimulates liver to release glucose	Stimulates slight glycogen synthesis
Skeletal muscles	Increases the strength of contractions and increases glycogenesis	No effect
Adipose tissue	Stimulates lipolysis	No effect
Sweat glands	Increase sweating	No effect
Adrenal glands	Stimulate secretion of epinephrine and norepinephrine	No effect
Digestive system	Decreases activity of glands and muscles as well as constricts sphincters	Increases peristalses and glandular secretion as well as relaxes sphincters
Kidneys	Activates the renin-angiotensin system and decreases urine production	No effect
Basal metabolism	Increases metabolism up to 100%	No effect
Eyes	Causes a dilation of pupils and causes relaxation of cilliary muscle for far sight	Causes constriction of the pupils
Mental activity	Increases mental activity	No effects

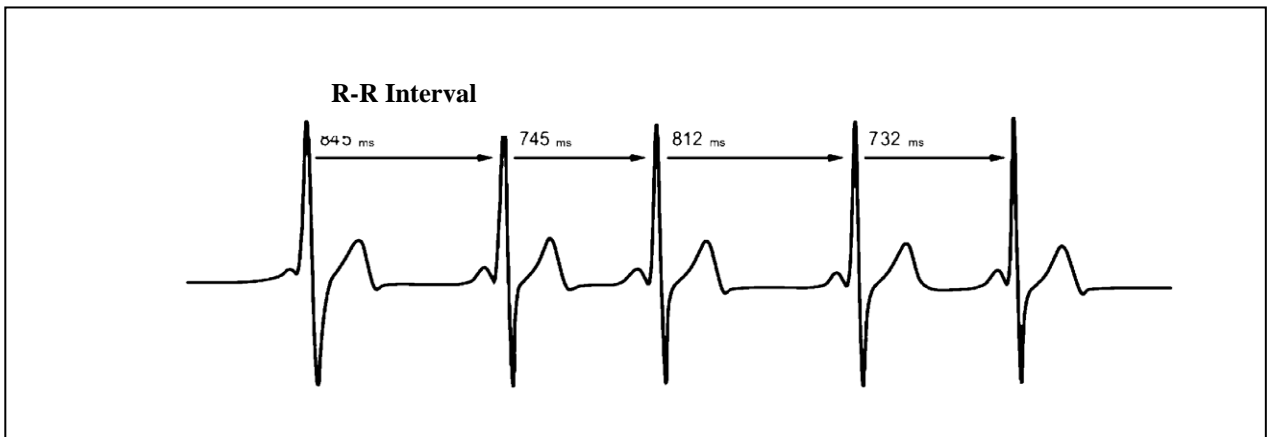
## **2.3 THE MEASUREMENT OF HEART RATE VARIABILITY AND HEART RATE RECOVERY**

### **2.3.1 The measurement of Heart Rate Variability**

From the previous section it is clear that a standardized method should be adopted in order to create the most applicable and sport specific protocol for the measurement of HRV and HRR. A protocol that allows researchers and sport practitioners to control for the factors that may influence the HRV and HRR measurements and as a consequence increase the reproducibility of HRV and HRR results, will be ideal for use in all HRV- and HRR-related research protocols. The next section will explain the protocols that are cited in literature and that have thus far been used to obtain HRV and HRR measurements.

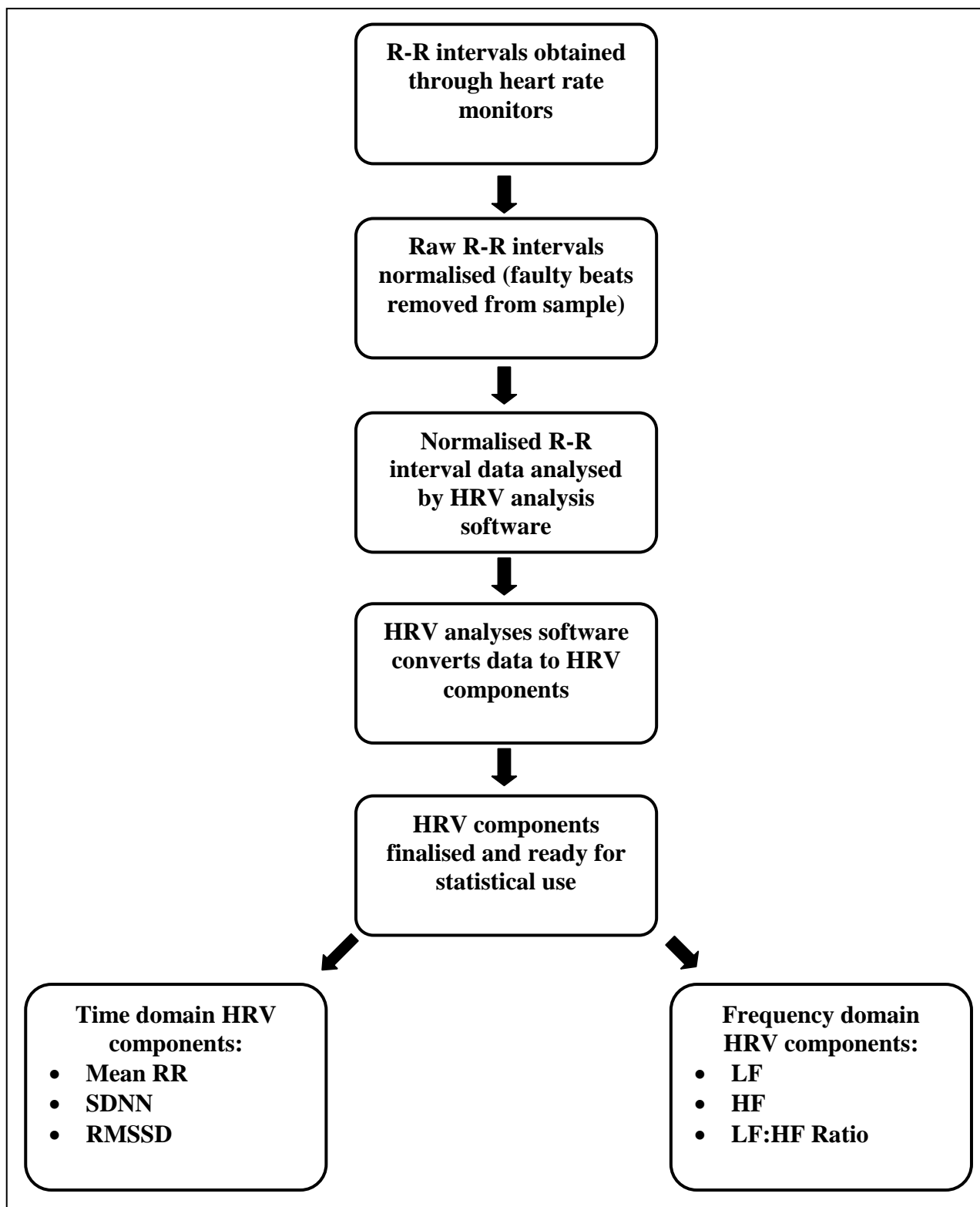
The use of an ambulatory electrocardiograph (ECG) is the favored and most accurate device to measure HRV (Lopes & White, 2006:41). Another way to obtain HRV measurements is by the use of Polar heart rate monitors which is also the most favored method in the sporting fraternity due to its practicality (Gamelin *et al.*, 2006:887). The Actiheart heart rate monitor can also be used to obtain accurate HRV readings (Kristiansen *et al.*, 2011:12). HRV measurements are obtained from an ECG (or other heart rate monitors) by applying the following steps (Makivic *et al.* 2013:105; Aubert *et al.*, 2003:897; Lee, 2001:58):

- Firstly, a high quality R-R interval measurement is obtained (Makivic *et al.* 2013:105). The time that elapses between two R-R cycles are used to determine the R-R intervals (Figure 2.1) (Makivic *et al.*, 2013:106). These measurements can last from a minimum of five minutes to twenty-four hours depending on the goal (Acharya *et al.*, 2006:1036; Aubert *et al.*, 2003:892). Precautions are taken to keep laboratory conditions standardized to avoid inconsistencies (refer to Table 2.4 for possible causes of inconsistencies).
- Secondly, HRV is quantified by analysing the R-R intervals through the use of modern computer technology (Makivic *et al.*, 2013:106; Pumprla *et al.*, 2002:3). The R-R intervals are analysed by HRV analysis software (through various complex algorithms and analysis techniques) and then converted to HRV parameters for interpretation.



**Figure 2.1:** An example of R-R intervals (in ms) measured from successive heart beats (Makivic *et al.* 2013:106)

The process of how HRV measurements are obtained is summarised in Figure 2.2.



**Figure 2.2:** The process of measuring HRV (most widely used HRV components) (Adapted from Makivic *et al.*, 2013:106; Aubert *et al.*, 2003:894)

From Figure 2.2 it is evident that HRV components are divided into two main branches namely time domain and frequency domain HRV parameters (Makivic *et al.*, 2013:105; Aubert *et al.*, 2003:892). All of the relevant components of HRV is listed and summarised in Table 2.3.

**Table 2.2: Summary of most common HRV components used for ANS evaluation (Makivic *et al.*, 2013:106; Tarvainen & Niskanen 2012:20; Aubert *et al.*, 2003:892)**

HRV parameter	Description	Link to ANS
<b>Time domain</b>		
R-R (ms)	Mean of R-R intervals	R-R changes correspond to changes in HR
SDNN (ms)	Standard deviation of R-R intervals	Reflects global cardiac variability
RMSSD (ms)	Squared root of the mean squared differences between successive R-R intervals	Represents PNS activity
<b>Frequency domain</b>		
Low frequency modulation (0.04-0.15Hz)	Peak band frequency of LF component	Reflects SNS and PNS activity
High frequency modulation (0.15-0.4Hz)	Peak band frequency of HF component	Reflects PNS activity
LF:HF ratio	Ratio and fractional distribution between LF and HF band powers	Index of the sympathovagal balance

LF                                      Low frequency power  
 HF                                      High frequency power  
 SNS                                    sympathetic nervous system  
 PNS                                    parasympathetic nervous

Regarding frequency domain parameters, high frequency components (HF) of the HRV signal are mediated by the PNS, whereas low frequency components (LF) are mediated by the SNS (Martinmaki *et al.*, 2008:546; Lewis *et al.*, 2007:35; Heidelin *et al.*, 2001:1397). As a result of the value of HF and LF, the ratio between HF and LF is used to quantify and provide an accurate index of sympathovagal balance (Lewis *et al.*, 2007:35; Lopes & White, 2006:41). This contention was also supported by Aubert *et al.* (2003:901) and Lewis *et al.* (2007:35) who showed that the LF:HF ratio increased during low intensity exercises which may be an indication of a withdrawal of the parasympathetic stimuli, and simultaneous enhancement of sympathetic stimuli.

Regarding time domain parameters, Aubert *et al.* (2003:894) stated that these parameters are easily computable by making use of simple statistical methods even from short time frames. Mean RR is a reflection of the changes in R-R interval time and also represents overall cardiac variability (Makivic *et al.* 2013:110). The following time domain parameters are however highly correlated with the HF component and represents parasympathetic modulation: SDNN represents total variability of cardiac autonomic activity and is significantly influenced by the duration of a measurement, thus SDNN components of same time duration should be considered when

analysing this HRV component (Makivic *et al.* 2013:105; Aubert *et al.* 2003:894). On the other hand RMSSD is considered to be a stable measure of parasympathetic activity (Plews *et al.*, 2013:775).

### 2.3.2 The measurement of Heart Rate Recovery

HRR measurements are most commonly obtained by means of wireless heart rate monitors and are usually measured for up to 30 minutes directly after the cessation of exercise (Borresen & Lambert, 2008:642). The methodology of measuring HRR is not as complicated as that of HRV. HRR measurements are usually expressed in the form of absolute (differences in heart rate beats between the exercise heart rate and post-exercise heart rate beats) or relative values (percentage decrease of heart rate from exercise heart rate to post-exercise heart rate) (Daanen *et al.*, 2012:257). The process of obtaining an HRR measurement is summarised in Figure 2.3:

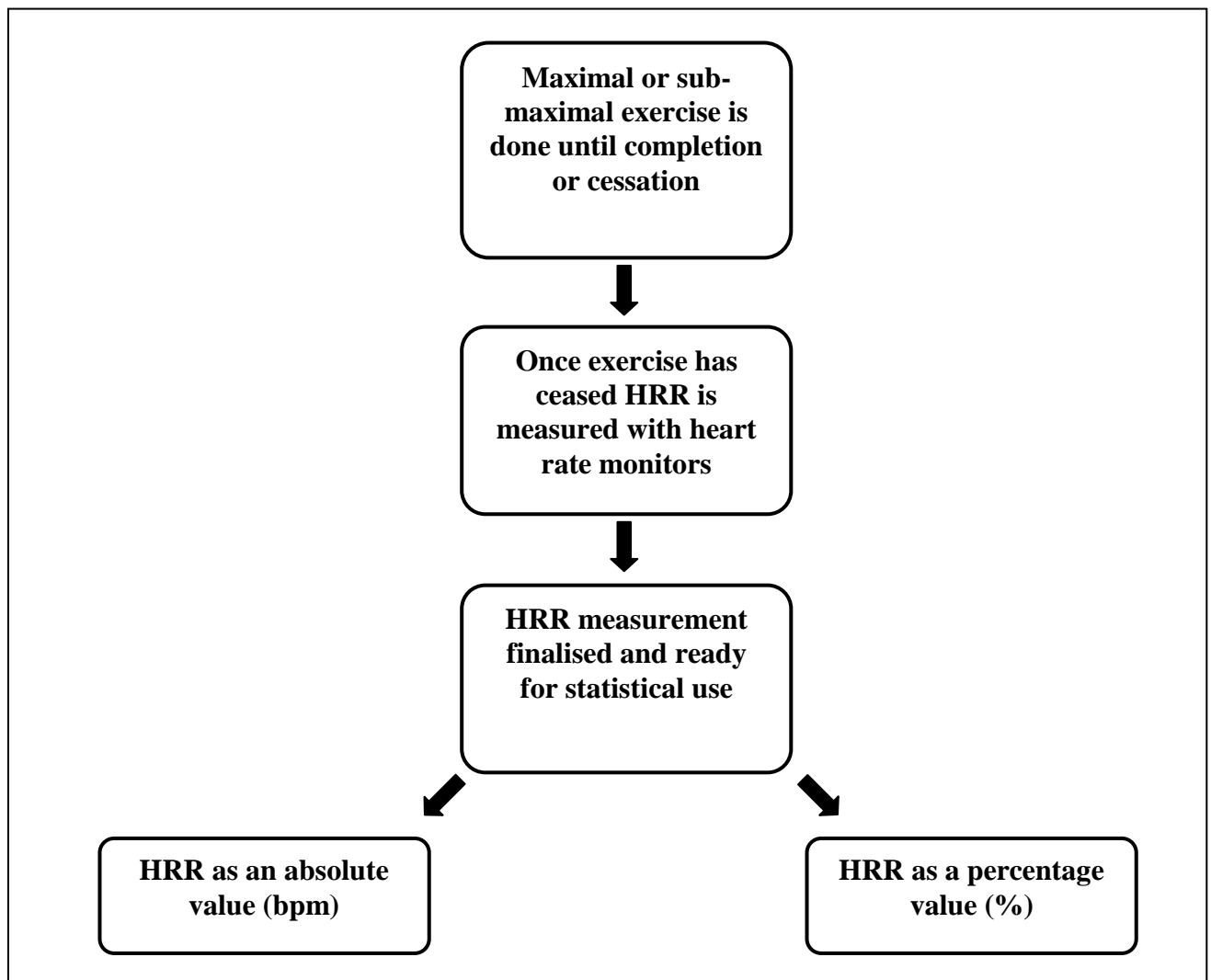


Figure 2.3: Process of obtaining a HRR measurement (Adapted from Daanen *et al.*, 2013:257)

Certain steps for obtaining HRV and HRR have therefore been predetermined and should be followed precisely in order to obtain accurate measurements.

### **2.3.3 The devices used for the measurement of Heart Rate Variability and Heart Rate Recovery**

Researchers prefer electrocardiograph apparatus (ECG) as the most accurate and favoured instrument to measure HRV in especially clinical studies where subjects are only required to be stationary and are not bound to time constraints (Gamelin *et al.*, 2006:887; Lopes & White, 2006:41). However, since the introduction of HRV in the sport and exercise setting the need to measure HRV in a shorter space of time and more easily has increased (Nunan *et al.*, 2009:243; Gamelin *et al.*, 2006:887). The most popular instrument to measure HRV as well as HRR in sport and exercise is the Polar heart rate monitor (Polar Electro, Kempele, Finland) due to its compact and user-friendly design as well as the benefit that measurements can be taken in almost any sporting environment (Gamelin *et al.*, 2006:887). A study by Gamelin *et al.* (2006) also proved that the Polar heart rate monitor (S810i) is a valid device to determine HRV, with strong, significant correlations ( $r = 0.99$ ,  $p < 0.05$ ) found between the Polar derived HRV parameters and ECG (Physiotrace Estaris, Lille, France) derived HRV values. Similarly, Nunan *et al.* (2009:243) also concluded that the Polar heart rate monitor is a valid and accurate device to measure HRV and HRR.

Although not as rugged as the Polar heart rate monitor, the Actiheart (CamNtech Ltd., Cambridge, U.K.) is another device that provides an accurate measurement of HRV when compared to ECG (Standard Holter ECG) (Kristiansen *et al.*, 2011:12). In this regard Kristiansen *et al.* (2011:12) showed that the Actiheart derived HRV values did not differ significantly ( $p < 0.05$ ) from the ECG derived HRV values. The study proved that the Actiheart is valid and accurate device and can be used to determine HRV. The Actiheart can also be used to measure long-term (up to twenty four hours) HRV and can be programmed to take measurements during certain time periods (Stalder *et al.*, 2010:459; Crouter *et al.*, 2008:705).

During the last few years more and more user-friendly and affordable devices and software for the measurement of HRV have emerged on the market. These devices and software are intended for personal use by athletes and coaches, and are becoming more popular (Wegerif, 2014; Jamieson, 2011). Devices such as the Bioforce Heart Rate Variability system and the Iathlete Heart Rate Variability system are currently the most favoured among the sporting fraternity (Valle, 2014). Both these devices use applications that can be downloaded on a mobile phone

and has wireless receivers from which the heart rate of the user can be obtained and analysed to calculate HRV. HRV values can also be stored and used as reference for future comparisons (Wegerif, 2014; Jamieson, 2011). However, despite the popularity of these devices no attempt has been made to proof the validity of these devices through scientific studies. It is therefore imperative that the accuracy and validity of these devices for measurement of HRV and HRR (where applicable) are first scientifically proven before it is accepted for use among athletes and sport related practitioners.

## **2.4 HEART RATE VARIABILITY AND HEART RATE RECOVERY AS INDICATORS OF AUTONOMIC NERVOUS SYSTEM FUNCTION AND THE APPLICATION OF THESE MEASUREMENTS IN SPORT AND EXERCISE**

The ability to quantify and assess ANS activity has been of great assistance to healthcare professionals and more recently the sporting fraternity (Plews *et al.*, 2013:774; Buchheit *et al.*, 2007:H8). In this regard, numerous studies have been undertaken to find and apply new and practical techniques to utilize the ANS parameters or indicators (Makivic *et al.*, 2013:108).

### **2.4.1 Heart Rate Variability**

HRV is considered to be a non-invasive, valid and effective means to assess ANS activity (Makivic *et al.*, 2013:105; Aubert *et al.*, 2003:892). Table 2.4.1 summarises the findings of studies which have investigated the use of HRV in sport and exercise settings.

**Table 2.3: Summary of HRV related studies in sport and exercise**

<b>Authors and date of publication</b>	<b>Number and gender of subjects</b>	<b>Brief methodology</b>	<b>HRV measurement methodology</b>	<b>Results and conclusions</b>
Sartor <i>et al.</i> (2013)	6 Male elite gymnasts	Gymnasts took part in a 10 week observational study. R-R intervals were taken for week 1, 3, 5, 7 and 9. Each individual training session over the 10 weeks was assessed by the Borg RPE scale and psychophysiological status (Fosters index).	R-R intervals obtained through the Polar RS800CX heart rate monitor. Measurements were taken in a supine position for 6 minutes with paced breathing maintained at 12 breaths per minute.	High frequency power percentage (HF%) and low frequency and high frequency power percentage (LF%:HF%) correlated significantly with the training load of the previous training day ( $r = 0.232$ , $r = -0.279$ ; $p < 0.05$ ) and R-R intervals correlated significantly with RPE and the Fosters index score ( $r = -0.384$ , $-0.227$ ; $p < 0.05$ ). It was therefore concluded that HRV could be useful in monitoring training load and psychophysiological status in elite male gymnasts.
Tian <i>et al.</i> (2013)	34 Elite female wrestlers	HRV indices were measured weekly in order to detect for non-functional overreaching (NFOR) or functional overreaching (FOR) during the training period before 11 major competitions.	RR intervals obtained through the Omegawave sport technology system. Measurement was taken in supine position for 2.5 minutes weekly before bedtime.	Researchers accurately diagnosed wrestlers experiencing FOR and (NFOR) using HRV indices (RMSSD- Squared root of the mean squared differences between successive RR intervals, SDNN- Standard deviation of RR intervals, LF-Low frequency power and HF-High frequency power). Wrestlers that experienced NFOR showed significant decreases in HRV as well as physical performance ( $p < 0.0001$ ). Thus HRV can possibly be used as a early warning system of overreaching in athletes

HF%	High frequency power expressed as percentage
LF%	Low frequency power expressed as percentage
LF%: HF%	Low and High frequency power percentage expressed as a ratio
FOR	Functional over reaching
NFOR	Non-functional over reaching
SDNN	Standard deviation of RR intervals
RMSSD	Squared root of the mean squared differences between successive RR intervals
HF	High frequency power
LF	Low frequency power
R-R intervals	Inter-beat intervals or R to R intervals

**Table 2.3 (cont.): Summary of HRV related studies in sport and exercise**

Authors and date of publication	Number and gender of subjects	Brief methodology	HRV measurement methodology	Results and conclusions
Esco & Williford (2013)	54 Young healthy male	Subjects were subjected to maximal exercise testing to determine $\dot{V}O_{2max}$ . HRV and skinfold measurements were taken beforehand. HRV recovery was measured directly after completion of the maximal exercise test and was measured again 30 minutes later.	R-R intervals were obtained through an electrocardiograph (ECG). HRV was measured in a supine position for 5 minutes with spontaneous breathing.	The sum of skinfolds was found to be the most significant predictor of resting HRV (HF and LF:HF ratio) and HRR ( $p < 0.05$ ). $\dot{V}O_{2max}$ were not found to be related to HRV after exercise. A greater sum of skinfolds was found to be related to a delayed HRV recovery back to baseline values. These findings suggested that a healthy body fat percentage is related to better cardiac autonomic regulation.
Boulloussa <i>et al.</i> (2013)	8 Male elite soccer players	The players were measured at the beginning of the pre-season and again 8 weeks later at the end of the pre-season. HRV was measured daily throughout the 8 weeks (4 times a week). The players were also subjected to the Yo-Yo intermittent recovery test 1 (Yo-Yo IR1) in week 1 and 8 of the pre-season period.	R-R intervals obtained through the Polar RS800 heart rate monitor. HRV was measured at night for 3 hours (00:00 - 03:00).	SDNN and SD2 (standard descriptor two) correlated significantly with Yo-Yo IR1 performance ( $r = 0.89$ , $p = 0.07$ and $r = 0.92$ , $p = 0.03$ ) for the measurements of week 8. Autonomic parameters were therefore significantly related to performance parameters. Also, HRV indices improved significantly over the pre-season training period (all of the correlations $r > 0.8$ , $p < 0.05$ ). The results supported the use of night time HRV for the evaluation of autonomic adaptations in professional soccer players.

- HF High frequency power
- LF Low frequency power
- LF:HF ratio Low and High frequency expressed as a ratio
- ECG Electrocardiograph
- $\dot{V}O_{2max}$  Maximal oxygen uptake
- SDNN Standard deviation of RR intervals
- Yo-Yo IR1 Yo-Yo Intermittent Recovery Test One
- SD2 standard descriptor two

**Table 2.3 (cont.): Summary of HRV related studies in sport and exercise**

<b>Authors and date of publication</b>	<b>Number and gender of subjects</b>	<b>Brief methodology</b>	<b>HRV measurement methodology</b>	<b>Results and conclusions</b>
Di Michele <i>et al.</i> (2012)	14 High-level swimmers (6 male; 8 female)	Swimmers completed the 7 x 200m front crawl test to determine anaerobic threshold. HRV and blood lactate concentration were measured continuously throughout the test. Swimmers had to try to swim their best times during this test.	R-R intervals obtained through the Polar S810i heart rate monitor. HRV measurements were divided into 90-second segments to better monitor changes in HRV. HRV measurements were correlated with blood lactate measurements.	HRV lactate anaerobic threshold parameters (HF power) correlated significantly with the lactate anaerobic threshold level ( $r = 0.93$ , $p < 0.05$ ), demonstrating that the anaerobic threshold can be determined from HRV.
Edmonds <i>et al.</i> (2012)	9 Male elite youth rugby league players	Players were observed during a training week and a game to determine the influence of this week on HRV. HRV was measured 2 days prior to the game, on the day of the game, 1 day, 2 and 4 days after the game.	R-R intervals obtained through the Polar heart rate monitor. HRV was measured for 5 minutes in a supine position with spontaneous breathing.	All of the time domain HRV measures showed no significant differences ( $p < 0.05$ ) over the 5 testing days. LF and LF:HF ratio was significantly higher on game day and remained elevated until 2 days after the game day ( $p < 0.05$ ). HF was significantly reduced on game day and remained lower until 2 days after the game ( $p < 0.05$ ). the results suggested that HRV is a valuable monitoring tool to evaluate ANS activity in young rugby league players

HF High frequency power  
 LF Low frequency power  
 LF:HF ratio Low and High frequency expressed as a ratio  
 R-R intervals Inter-beat intervals or R to R intervals

**Table 2.3 (cont.): Summary of HRV related studies in sport and exercise**

<b>Authors and date of publication</b>	<b>Number and gender of subjects</b>	<b>Brief methodology</b>	<b>HRV measurement methodology</b>	<b>Results and conclusions</b>
Fronzo <i>et al.</i> (2012)	7 Male amateur basketball players	Players were measured during the play-off phase of their competitive season. This phase lasted 7 weeks and HRV was measured on the mornings of match days. HRV was then compared with match performances.	R-R intervals obtained through an ECG. HRV was measured for 10 minutes in a resting supine position.	HF accounted for 15% ( $p < 0.05$ ) of the variance in match performance. The authors therefore concluded that HRV when expressed as HF is positively related to players' match performances. In particular higher HF values were associated with increased match performances.
Ke-tien (2012)	24 Male national rugby players	Players participated in an 8-week cardio-respiratory endurance training program. Throughout this time the players' HRV were measured 5 times. $\dot{V}O_{2max}$ were measured at the beginning and end of the 8-week training period.	R-R intervals were obtained through an ECG. HRV was measured in a supine position with controlled breathing for 15 minutes.	The cardio-respiratory endurance training period significantly increased the LF:HF ratio ( $p < 0.05$ ). HF also improved significantly throughout the cardio-respiratory endurance training period ( $p < 0.05$ ). The results suggested that an 8-week endurance based training program improves cardiac regulation in rugby players.

HF High frequency power  
 LF Low frequency power  
 LF:HF ratio Low and High frequency expressed as a ratio  
 ECG Electrocardiograph  
 R-R intervals Inter-beat intervals or R to R intervals  
 $\dot{V}O_{2max}$  Maximal oxygen uptake

**Table 2.3 (cont.): Summary of HRV related studies in sport and exercise**

Authors and date of publication	Number and gender of subjects	Brief methodology	HRV measurement methodology	Results and conclusions
Oliveira <i>et al.</i> (2012)	11 Male high-level futsal players	Players were measured on three separate occasions: 1) beginning of pre-season training (M1); 2) after 3 weeks during the pre-season (M2). 3) after 3 months in the regular season (M3). During these measurements resting HRV was taken and the players were subjected to the Yo-Yo intermittent recovery test 1 (Yo-Yo IR1) the next day.	R-R intervals obtained through the Polar RS800 heart rate monitor. HRV measurements were taken in 5 minute sessions at rest in a seated position with spontaneous breathing.	Compared to M1 HRV values, R-R mean ( $p = 0.003$ ), RMSSD ( $p = 0.001$ ) and HF ( $p = 0.03$ ) significantly improved at M2. No significant improvements were found at M3. Thus HRV did not improve after the initial 3 weeks of pre-season training. The results showed that short-term HRV can be improved with a short-term pre-season training program. The results also suggested that frequent monitoring of HRV indices can assist with the identification of individual training adaptation.
Hap <i>et al.</i> (2011)	8 Male volleyball players	The players were participating in a training camp of 1 week. HRV was measured throughout this week. HRV was then compared to training load during this week.	HRV was measured in a supine and standing position for 5 minutes with spontaneous breathing.	Two players who showed increased ANS activity also experienced an above average training intensity throughout the week. Overall, players who exhibited average ANS activity also experienced corresponding average training intensities throughout the week. A decrease in ANS activity was also experienced by two players, who could not maintain training intensities throughout the week. These results suggested that training efficiency can be increased and overtraining can be avoided if longitudinal ANS activity is monitored in volleyball players.

- HF High frequency power
- LF Low frequency power
- RMSSD Squared root of the mean squared differences between successive RR intervals
- Yo-Yo IR1 Yo-Yo Intermittent Recovery Test One
- R-R intervals Inter-beat intervals or R to R intervals
- M1 Beginning of pre-season training
- M2 After 3 weeks during the pre-season
- M3 After 3 months in the regular season

**Table 2.3 (cont.): Summary of HRV related studies in sport and exercise**

Authors and date of publication	Number and gender of subjects	Brief methodology	HRV measurement methodology	Results and conclusions
Bricout <i>et al.</i> (2010)	8 Male adolescent soccer players	HRV was measured every week for five months during the adolescents' soccer season. During each week players were measured 3 times: after a rest day, after a training day and after a match day.	R-R intervals obtained through the Polar RS800 heart rate monitor. HRV was measured while players were sleeping each night.	They found that HRV was lower after a match day than after a rest day whereas the HF component showed a significant decrease between rest days and after matches ( $p < 0.05$ ). The LF:HF ratio was lower at rest, higher after training and displayed a significant increase after matches ( $p < 0.05$ ). This was an indication that parasympathetic stimulation was not significantly altered during training days but showed a significant decrease after a match day. In conclusion, HRV indices (HF and LF:HF ratio) serve as unique measurements for diagnosing the state of fatigue and if utilized correctly the deleterious effects of overtraining on young sportsmen could be avoided.
Buchheit <i>et al.</i> (2010a)	14 Male recreational runners	Runners were subjected to an 8-week training intervention. Resting HRV indices were measured daily. Maximal aerobic speed and 10 km running performance were assessed before and after the intervention.	R-R intervals obtained through the Polar S810i heart rate monitor. HRV measurements were taken in 5 minute sessions at rest with spontaneous breathing.	All correlations that pertained to changes in HRV indices (RMSSD), maximal aerobic speed and running performance were significant. ( $r > 0.60$ ; $p < 0.05$ ). The study confirmed the interdependency between cardiac autonomic function and aerobic running performance. It was therefore concluded that resting and post exercise HRV may possibly serve as predictors of changes in aerobic running performance.

RMSSD                      Squared root of the mean squared differences between successive RR intervals  
 HF                            High frequency power  
 LF                            Low frequency power  
 LF:HF ratio                Low and High frequency expressed as a ratio  
 R-R intervals              Inter-beat intervals or R to R intervals

**Table 2.3 (cont.): Summary of HRV related studies in sport and exercise**

Authors and date of publication	Number and gender of subjects	Brief methodology	HRV measurement methodology	Results and conclusions
Buchheit <i>et al.</i> (2010b)	36 Young male soccer players	Players participated in a 3-week training camp. During this time the players completed a 5 minute sub-maximal run every morning as part of their warm-up. HRV was measured during this time. Two weeks prior to the camp the players were subjected to a graded field running test to estimate maximal aerobic speed (MAS) and maximal heart rate (HRmax).	R-R intervals obtained through the Polar S810i heart rate monitor. HRV measurements were taken in 3-minute sessions during passive recovery with spontaneous breathing.	HRV (Ln-RMSSD- natural logarithm applied for RMSSD) correlated to MAS ( $r = -0.52$ , $p = 0.002$ ). The results showed that HRV is a valid marker of aerobic performance in young soccer players.

RMSSD                      Squared root of the mean squared differences between successive RR intervals  
 Ln-RMSSD                logarithm applied for RMSSD  
 MAS                        Maximal aerobic speed  
 HRmax                     Maximal heart rate  
 R-R intervals            Inter-beat intervals or R to R intervals

**Table 2.3 (cont.): Summary of HRV related studies in sport and exercise**

Authors and date of publication	Number and gender of subjects	Brief methodology	HRV measurement methodology	Results and conclusions
Cipryan & Stejskal (2010)	18 Male ice hockey players	The study took place over a 2-month conditioning period. HRV was measured twice a week. Players were divided into 2 groups: junior group (average of 18 years) and adult group (average of 26 years).	R-R intervals obtained through the VarCor PF7 heart rate monitor. HRV was measured in 5-minute sessions in a supine and standing position with spontaneous breathing.	Junior players showed an above average adaption capacity to increased exercise ( $p < 0.05$ ). They could therefore endure a much more intensive training load from an ANS point of view. The adult group also showed adequate ANS recovery after training sessions ( $p < 0.05$ ). However in a few cases less fit players were close to overreaching. Some of the more fit players weren't affected as much by rigorous group training from an ANS point of view. The study concluded by stating that players should be placed into groups with similar ANS profiles so that training efficiency can be increased.
Schmitt <i>et al.</i> (2008)	11 Elite cross country skiers (6 women; 5 men)	Skiers completed a high-low and low-low training intervention lasting 18 days. $\dot{V}O_{2max}$ and HRV were measured before and after the training intervention.	R-R intervals obtained through the Polar S810i heart rate monitor. Measurement was taken in supine position for 8 minutes and 6 minutes in standing position at paced breathing.	Changes in aerobic capacities ( $\dot{V}O_2$ at respiratory compensation point (RCP)) correlated significantly with HF, LF and total power TP ( $r = 0.48$ , $r = 0.68$ and $r = 0.53$ ; $p < 0.05$ ), thereby confirming the relationship between changes in aerobic capacity and HRV.

- VT1                      Ventilatory threshold one
- VT2                      Ventilatory threshold two
- HF                        High frequency power
- LF                        Low frequency power
- TP                        Total power
- RCP                      Respiratory compensation point
- $\dot{V}O_{2max}$                 Maximal oxygen uptake
- $\dot{V}O_2$                       Oxygen uptake
- R-R intervals           Inter-beat intervals or R to R intervals

**Table 2.3 (cont.): Summary of HRV related studies in sport and exercise**

Authors and date of publication	Number and gender of subjects	Brief methodology	HRV measurement methodology	Results and conclusions
Seiler <i>et al.</i> (2007)	9 Highly trained and 8 recreational trained male runners	The runners were divided into 2 groups: highly trained (HT) and trained (T) runners. Runners were subjected to the following exercise intensities: below ventilatory threshold one (VT1) for 60 and 120 minutes respectively; 30 minutes between VT1 and VT2 intensities and 60 minutes above the VT2 during four separate training sessions. HRV was measured before and after to compare ANS recovery of the 2 groups	R-R intervals obtained through the Polar S810i heart rate monitor. Measurement was taken in 5 minute sessions while breathing spontaneously. HRV was measured at 5, 15, 30, 60, 90, 120, 180 and 240 minutes after completion. Food and fluid intake was controlled for every subject during the recovery period.	The HRV results showed that the HT athletes' ANS recovery were significantly quicker than that of the T athletes' after each of the training sessions. Furthermore, after the high intensity exercise above the VT2 intensity, the HT athletes took 5 minutes to exhibit pre-exercise HRV values (RMSSD' LF power and HF power), compared to the recreational athletes, who took 60 to 90 minutes longer to exhibit pre-exercise HRV values ( $p < 0.05$ ). In view of these results, the authors concluded that highly trained athletes experience faster ANS responsiveness and recovery after exercise compared to regular athletes and that the correct utilization of HRV assessment may help HT athletes to organise day-to-day distributions in training intensity.

- LF                                      Low frequency power
- VT1                                    Ventilatory threshold one
- VT2                                    Ventilatory threshold two
- RMSSD                                Squared root of the mean squared differences between successive RR intervals
- $\dot{V}O_{2max}$                             Maximal oxygen uptake
- R-R intervals                        Inter-beat intervals or R to R intervals
- HT                                      Highly trained
- T                                        Trained

**Table 2.3 (cont.): Summary of HRV related studies in sport and exercise**

Authors and date of publication	Number and gender of subjects	Brief methodology	HRV measurement methodology	Results and conclusions
Kiviniemi <i>et al.</i> (2007)	26 male Recreational runners	Runners were divided into the following groups: predefined training group (n = 8) which trained in accordance with a set training program (six days a week); HRV guided training group (n = 9) which trained according to daily HRV profile and a control group (n = 9) who trained only 4 days per week. Each group completed a 4 week training period. $\dot{V}O_{2max}$ was measured before and after the training period.	R-R intervals obtained through the Polar S810i heart rate monitor. Measurements were taken every morning during the training period for 5 minutes sitting and 5 minutes standing. Pre- to post-HRV was also compared to baseline values. In cases where HRV showed a decrease, low intensity training or rest was prescribed.	The training group who used HRV (HF power) to guide the training intensity throughout the training period showed a significant increase in running velocity compared to non-HRV guided training group (p = 0.048). It was therefore concluded that cardiorespiratory fitness can be improved with HRV as a training prescription tool.

HF High frequency power  
 $\dot{V}O_{2max}$  Maximal oxygen uptake  
 R-R intervals Inter-beat intervals or R to R intervals

**Table 2.3 (cont.): Summary of HRV related studies in sport and exercise**

Authors and date of publication	Number and gender of subjects	Brief methodology	HRV measurement methodology	Results and conclusions
Gamelin <i>et al.</i> (2007)	10 Healthy young men	Participants were subjected to a 12-week intensive aerobic training program. Afterwards subjects underwent an 8 week detraining phase where no exercise was done. HRV was measured along with an incremental exercise test at the beginning and end of 12-week training period. HRV was then measured again on weeks 2, 4 and 8 of the detraining phase.	R-R intervals obtained through the Polar S810i heart rate monitor. Measurements were taken in a supine position for 5 minutes and 10 minutes in a 60° head tilt position with paced breathing.	A significant increase in HRV (LF, HF and LF:HF ratio) was found after the training program compared to baseline values (before training program) ( $p < 0.05$ ). HRV (LF, HF and LF:HF ratio) showed a significant moderate decrease after only 2 weeks of detraining ( $p > 0.05$ ). The results suggest that aerobic training enhances cardiac autonomic control after 12 weeks of aerobic training. However, 2 weeks of detraining is enough to cause decreases in training induced adaptations.

HF High frequency power  
 LF Low frequency power  
 LF:HF ratio Low and High frequency expressed as a ratio  
 R-R intervals Inter-beat intervals or R to R intervals

**Table 2.3 (cont.): Summary of HRV related studies in sport and exercise**

Authors and date of publication	Number and gender of subjects	Brief methodology	HRV measurement methodology	Results and conclusions
Cottin et al. (2006)	11 Male cyclists	The cyclists executed an incremental exhaustive test on a cycle ergometer while HRV was measured. The well established ventilatory- ( $\dot{V}_E/\dot{V}O_2$ ; $\dot{V}_E/\dot{V}CO_2$ ) as well as experimental HRV-based (HF peak spectral power) detection methods were used to determine both ventilatory thresholds of the cyclists.	R-R intervals were obtained through an ECG. HRV was measured during the incremental exhaustive test in 20-second periods and in synchronisation with ventilatory data.	The researchers found no significant difference between the HRV-based (HF) and conventional ventilatory-based thresholds expressed as a percentage of $\dot{V}O_{2peak}$ (VT1: $r = 0.94$ ; $p < 0.05$ and VT2: $r = 0.97$ ; $p < 0.01$ ). The conclusion that was therefore made is that HRV determined from R-R intervals could be used to estimate ventilatory thresholds during exercise in well-trained cyclists.

- $\dot{V}_E/\dot{V}O_2$  Minute ventilation over oxygen consumption
- $\dot{V}_E/\dot{V}CO_2$  Minute ventilation over carbon dioxide production
- $\dot{V}O_{2peak}$  Peak oxygen uptake
- VT1 Ventilatory threshold one
- VT2 Ventilatory threshold two
- HF High frequency power
- ECG Electrocardiograph
- R-R intervals Inter-beat intervals or R to R intervals

**Table 2.3 (cont.): Summary of HRV related studies in sport and exercise**

<b>Authors and date of publication</b>	<b>Number and gender of subjects</b>	<b>Brief methodology</b>	<b>HRV measurement methodology</b>	<b>Results and conclusions</b>
Earnst <i>et al.</i> (2004)	8 Professional male cyclists	Cyclists competed in a 3-week stage race during which HRV was measured twice. Baseline HRV was also measured 2 days prior to the competition.	R-R intervals obtained through the Polar S810i heart rate monitor. Measurements were taken in a supine position for 15 minutes with spontaneous breathing.	The results showed that HRV components inversely correlated with exertions levels: RMSSD ( $r = -0.93$ ; $p < 0.001$ ); SDNN ( $r = -0.94$ ; $p < 0.001$ ); LF power ( $r = -0.79$ ; $p < 0.02$ ); HF power ( $r = -0.94$ ; $p < 0.001$ ) and Total power ( $r = -0.97$ ; $p < 0.001$ ). The results suggested that HRV were directly related to training intensity and volume. HRV is therefore strongly affected by chronic exposure to heavy exertion.

SDNN                                      Standard deviation of RR intervals  
 RMSSD                                    Squared root of the mean squared differences between successive RR intervals  
 HF                                            High frequency power  
 LF                                            Low frequency power  
 R-R intervals                            Inter-beat intervals or R to R intervals

The results that are presented in Table 2.3 show that HRV has the potential to be used as a monitoring, evaluation and prediction tool of training load and responses as well as for the measurement of sport performance in a variety of sport situations. In this regard the research results (Table 2.3) suggest that HRV can be successfully used to monitor psychophysiological status, overreaching status, overtraining and training load in elite male gymnasts and female wrestlers (Sartor *et al.*, 2013:2789; Tian *et al.*, 2013:1517; Bricout *et al.*, 2010:115). Research also show that HRV is related to anaerobic threshold parameters such as respiratory compensation point ( $r = 0.48$ ,  $p < 0.05$ ), lactate threshold ( $r = 0.93$ ,  $p < 0.05$ ), ventilatory threshold ( $r = 0.97$ ,  $p < 0.01$ ), and Yo-Yo IR1 performance ( $r = 0.92$ ,  $p = 0.03$ ) as well as maximal aerobic speed ( $r = -0.52$ ,  $p < 0.05$ ) in both team (elite male soccer and national male rugby players) and individual sport participants (high-level swimmers, elite cross country skiers, recreational male runners and cyclists) (Boullosa *et al.*, 2012:405; Di Michele *et al.*, 2012:3063; Ke-tien 2012:1223; Buchheit *et al.*, 2010:1164; Schmitt *et al.*, 2008:302; Cottin *et al.*, 2006:565). HRV also seems to be significantly related ( $p < 0.05$ ) to body fat percentage and recovery time after exercise in highly trained runners and healthy young males (Esco & Williford, 2013:394; Seiler *et al.*, 2007:1370). HRV has also been used to successfully monitor ANS activity during match and training conditions in order to mediate and individualize training loads for more efficient training in male basketball, volleyball, ice hockey players and recreational male runners (Fronzo *et al.*, 2012:S1; Hap *et al.*, 2011:35; Cipryan & Stejskal, 2010:35; Kiviniemi *et al.*, 2007:747).

#### **2.4.2 Heart Rate Recovery**

Another non-invasive assessment technique that can be used to evaluate ANS activity is HRR (Buchheit *et al.*, 2007:H8). Table 2.4 summarises the findings of studies which have investigated the use of HRR in sport and exercise settings.

**Table 2.4: Summary of HRR related studies in sport and exercise**

Authors and date of publication	Number and gender of subjects	Brief methodology	HRR related methodology	Results and conclusions
Boullosa <i>et al.</i> (2013)	8 Male elite soccer players	Players were measured at the beginning of the pre-season and again 8 weeks later at the end of the pre-season. During these measurements the players were subjected to small-sided sport specific soccer games during which HR data was collected. Ultra short HRR was taken during these small-sided sport specific soccer games. The players were also subjected to the Yo-Yo intermittent recovery test 1 (Yo-Yo IR1) in week 1 and 8 of pre-season.	HRR was only calculated when player maintained 85% of HRmax for a period longer than 20 seconds. After this was achieved the player actively recovered. During this time HRR was calculated for the next 20 seconds.	HRR improved significantly during the small-sided sport specific soccer games after the pre-season ( $p < 0.05$ ). This reflects greater parasympathetic reactivation during active recovery. The results support the practicality of HRR for the evaluation of autonomic adaptations in professional soccer players.

Yo-Yo IR1

Yo-Yo Intermittent recovery test one

HRmax

Maximal heart rate

**Table 2.4 (cont.): Summary of HRR related studies in sport and exercise**

Authors and date of publication	Number and gender of subjects	Brief methodology	HRR related methodology	Results and conclusions
Dupuy <i>et al.</i> (2013)	11 Male endurance runners	Runners were subjected to a 2-week overloading period (training load was increased by 100%) designed to induce an overreached state. A maximal graded exercise test and a continuous sub-maximal running test (85% of peak treadmill speed) were completed by the runners before and after the 2-week period in order to determine HRR. The runners then completed a taper period of 1 week.	HRR was taken directly after a maximal exercise test for 60 seconds in a passive position.	HRR was significantly increased ( $p < 0.05$ ) after the maximal graded exercise test following the 2-week overloading period. However, no significant changes in HRR were found after the continuous sub-maximal running test. HRR returned to baseline values (before 2-week overload period) after the 1 week taper period. The results show that cardiac autonomic control is altered by a 2-week overloading period.
Henriquez <i>et al.</i> (2013)	18 Male wrestlers (10 highly trained and 8 moderately trained)	Wrestlers were subjected to a maximal incremental exercise test. HRR was taken and compared between highly (HT) and moderately trained (MT) wrestlers.	HRR was taken for 60 seconds directly after cessation of exercise.	HRR was shown to be significantly different between HT and MT ( $p < 0.01$ ). HT wrestlers also possessed a faster HRR than MT wrestlers ( $p < 0.05$ ). The results suggested that HRR after 60 seconds is related to state of training in wrestlers.

HT Highly trained  
 MT Moderately trained

**Table 2.4 (cont.): Summary of HRR related studies in sport and exercise**

Authors and date of publication	Number and gender of subjects	Brief methodology	HRR related methodology	Results and conclusions
Lee & Mendoza (2012)	19 Endurance athletes (8 male, 11 female)	Endurance athletes were subjected to a maximal graded incremental exercise test. HRR was taken and the relationship between this measurement and aerobic fitness as well as physical activity (as assessed <i>via</i> a questionnaire) was determined.	HRR was taken directly after cessation of the maximal graded incremental exercise test for 5 minutes while athletes actively cooled down on the treadmill at a very low intensity.	HRR significantly correlated with physical activity ( $r = 0.51$ ; $p = 0.039$ ) and $\dot{V}O_{2max}$ ( $r = 0.67$ ; $p = 0.003$ ) and respectively. The results suggested that HRR may be a valid marker of fitness as well as a marker for autonomic recovery.
Gocentas <i>et al.</i> (2011)	8 Male high-level basketball players	Basketball players completed a 3.5 minute intensive sport specific exercise drill at the end of team practise. HRR was measured after the drill was completed. The procedure was repeated over 4 consecutive practises over the course of the competitive season. Players were ranked according to sport specific efficiency (as determined by sport specific drill execution) and game time exposure).	HRR was taken directly after the drill was completed for 60 seconds.	Players that were most efficient during the sport specific drill and had the most competition time also showed a decrease in HRR over the competitive season. The players that were least inefficient during the sport specific drill and had the least competition time showed an increase in HRR. In conclusion, these results suggested that HRR is useful to determine functional status in basketball players throughout a competitive season.

$\dot{V}O_{2max}$

Maximal oxygen uptake

**Table 2.4 (cont.): Summary of HRR related studies in sport and exercise**

Authors and date of publication	Number and gender of subjects	Brief methodology	HRV measurement methodology	Results and conclusions
Ostojic <i>et al.</i> (2011)	32 Male soccer players	Players performed a maximal incremental exercise test in order to reach HRmax. Immediately after cessation of exercise the athletes' HRR were taken.	HRR was taken every 10 seconds up until 60 seconds in a supine position. Players were immediately transferred to a supine position after exercise ceased.	The players with high aerobic power ( $\dot{V}O_{2max}$ of > 60 ml/kg/min) exhibited significant faster HRR at 10 and 20 sec intervals ( $p < 0.05$ ) compared to the players with lower aerobic power ( $\dot{V}O_{2max}$ of < 50ml/kg/min). The study therefore concluded that aerobic power along with autonomic regulation plays a role in the ultra short-term cardiovascular response to exercise.
Buchheit <i>et al.</i> (2010a)	14 Recreational male runners	Runners were subjected to an 8-week training intervention. HRR indices were measured every 2 weeks. Maximal aerobic speed and 10 km running performance were assessed before and after the intervention.	HRR was taken for 5 minutes after the running performances.	HRR showed a significant negative relationship with 10 km running performance ( $r = 0.54$ ; $p < 0.05$ ). Therefore, these results suggested that post-exercise heart rate indices have the potential to serve as indicators of aerobic endurance performance.

HRmax

Maximal heart rate

$\dot{V}O_{2max}$

Maximal oxygen uptake

**Table 2.4 (cont.): Summary of HRR related studies in sport and exercise**

Authors and date of publication	Number and gender of subjects	Brief methodology	HRR related methodology	Results and conclusions
Buchheit <i>et al.</i> (2010b)	36 Young male soccer players	Players participated in a 3-week training camp. During this time the players completed a 5-minute sub-maximal run every morning as part of their warm-up, HRR was taken during this time. Two weeks prior to the camp the players were subjected to a graded field running test to estimate maximal aerobic speed (MAS) and maximal heart rate (HRmax).	HRR was taken for 60 seconds during passive recovery directly after exercise.	No correlation was found between HRR and MAS as well as total activity time on the field, which led the researchers to conclude that the day-to-day variation of HRR in young soccer players is not as easily affected as with more mature soccer players.
Haddad <i>et al.</i> (2010)	12 Healthy male adults	Subjects were tested on 3 separate occasions each testing consisting of an all out 30 second Wingate test which was followed by 5 minutes of seated recovery and by a sub-maximal exercise test. After this the subjects passively recovered by either cold water immersion, thermoneutral water immersion or no water immersion. HRR was measured during the final recovery periods.	HRR was taken for 60 seconds directly after completion of the sub-maximal exercise test in a seated position.	Compared to the no water immersion recovery, HRR was accelerated in both water immersion recovery periods with cold water ( $p = 0.017$ ) and thermoneutral water ( $p = 0.003$ ) significantly increasing HRR. In conclusion, water immersion can therefore facilitate parasympathetic stimulation which in turn can increase autonomic recovery.

MAS Maximal aerobic speed

HRmax Maximal heart rate

**Table 2.4 (cont.): Summary of HRR related studies in sport and exercise**

Authors and date of publication	Number and gender of subjects	Brief methodology	HRV measurement methodology	Results and conclusions
Lamberts <i>et al.</i> (2010)	14 Well-trained male cyclists	Subjects completed a 4-week high intensity (HIT) program before the study and were divided into 2 groups according to subjects who showed an increase in HRR and subjects who showed a decrease in HRR throughout the HIT program. HRR and its relation to performances were subsequently analysed.	HRR was taken for 60 seconds directly after an exercise on a bicycle. Once cyclists completed time trail they were instructed to bend over in a standing position whilst resting their arms on the handlebars of their bicycles.	Subjects who displayed an increase in HRR during the HIT program exhibited a significantly higher average power output during the 40km time trial ( $p = 0.01$ ) as well as a faster 40km trial time ( $p = 0.059$ ) compared to subjects who displayed a decrease in HRR during the HIT program. In conclusion, these findings suggested that HRR has the potential to serve as a measurement to monitor changes in endurance cycling performance.
Borresen & Lambert (2007)	28 physically active adults (12 = men, 16 = women)	Subjects trained for 2 weeks on their own. At the end of this period subjects were divided into 3 groups: Group I who increased their training load over the 2 weeks; Group D who decreased their training load over the 2 weeks; Group S whose training load remained the same over the 2 weeks. The percentage HRR from sub-maximal exercise was determined before and after every week of the training period.	The 1 minute percentage HRR was taken directly after a standardized sub-maximal shuttle run test while subjects were standing.	Group I showed a significant decrease ( $p < 0.05$ ) in mean percentage HRR after the 2 weeks compared to group D who showed significant increase in mean percentage HRR after the 2 weeks. For group S no significant difference in percentage HRR was observed. Overall the results therefore showed that HRR responds to acute changes in training load and that this ANS indicator can be used to determine the body's exercise capacity.

HIT

High Intensity training program

**Table 2.4 (cont.): Summary of HRR related studies in sport and exercise**

Authors and date of publication	Number and gender of subjects	Brief methodology	HRR related methodology	Results and conclusions
Otsuki <i>et al.</i> (2007)	12 Male strength trained and 12 endurance trained athletes and 12 sedentary adults	The athletes and sedentary control group performed a maximal oxygen uptake test on a bicycle ergometer. The following day the athletes performed 8 minutes of sub-maximal exercise (40% of $\dot{V}O_{2max}$ ). HRR was taken directly after each of these tests.	HRR was taken in die first 30 seconds after exercise in a standing position.	Both strength and endurance trained athletes showed a significant faster HRR than the control group ( $p < 0.05$ ). However there were no significant differences between the HRR in the strength and endurance trained athletes. The conclusion that was therefore drawn, is that both strength and endurance trained athletes possess an accelerated HRR.

$\dot{V}O_{2max}$

Maximal oxygen uptake

The results in Table 2.4 indicate that HRR also has the potential to serve as a measurement tool to monitor, evaluate and predict training response as well as performance in a sport and exercise setting. Various authors have for example showed that HRR can be used to determine seasonal training program cardiovascular and autonomic adaptations in team sport participants as well as to determine the effectiveness (as evaluated by the improvement or change in HRR parameters) of endurance and sport specific training programs in soccer and basketball players (Boullosa *et al.*, 2013:405; Gocentas *et al.*, 2011:14; Ostojic *et al.*, 2011,108; Buchheit *et al.*, 2010:1163) as well as in individual sport participants (well-trained male cyclists) and physically active adults (Lamberts *et al.*, 2010:453; Borresen & Lambert, 2007:509). A significant slower HRR was also significantly associated ( $p < 0.05$ ) with overtraining in male endurance runners (Dupuy *et al.*, 2013:203). Further analyses of literature revealed that a faster HRR is related to  $\dot{V}O_{2\max}$  ( $r = 0.67$ ;  $p = 0.003$ ), 10km timed running performance ( $r = 0.54$ ,  $p < 0.05$ ) and significant changes ( $p < 0.05$ ) in exercise capacity of endurance athletes, recreational runners and physically active adults (Lee & Mendoza, 2012:2764; Buchheit *et al.*, 2010:1163; Borresen & Lambert, 2007:509). HRR has also been used to assess recovery (faster HRR is a reflection of better recovery) and to substantiate the significant positive effects of cold water immersion ( $p = 0.017$ ) and thermoneutral water ( $p = 0.003$ ) on recovery status in healthy adult males (Haddad *et al.*, 2010:114). Furthermore, Henriquez *et al.* (2012:113) and Otsuki *et al.* (2007:368) proved that strength trained athletes and wrestlers exhibited a significantly ( $p < 0.05$ ) increased HRR which is normally associated with endurance athletes.

The above-mentioned sections therefore provide proof that the use of HRV and HRR in sport and exercise settings is already well-established and that the inclusion of these measurements in existing testing protocols for evaluating athletes, will allow sport practitioners to obtain a better picture of athletes' physical, motor performance and psychological profiles.

## **2.5 LIMITATIONS OF USING HRV AND HRR AS INDICATORS OF ANS ACTIVITY**

The previous section discussed the need and purpose of the ANS related parameters (HRV and HRR) in sport and exercise. However, despite the potential of HRV and HRR to serve as indicators of ANS activity several limitations of using these measurements need to be considered in view that limitations may possibly lead to inaccurate measurements and wrong conclusions. The next section will therefore be dedicated to the limitations of using HRV and HRR measurements to evaluate ANS activity. As a start to this discussion, factors that are most likely to influence short-term HRV and HRR in sport and exercise are presented in Table 2.5.

**Table 2.5: Summary of factors that may influence short-term ANS activity in sport and exercise**

Authors and date of publication	Purpose/s of the study	Methodology	Influencing factor	Results and conclusions
Saboul <i>et al.</i> (2013)	To compare daily variations of HRV parameters between controlled breathing (CB) and spontaneous breathing (SB) in 10 healthy male runners	HRV was taken daily in the supine, low-light and fasting state for 5 minutes. One measurement during CB and one during SB. Time domain and frequency domain indices were analysed through R-R intervals (Suunto T6d) and HRV analysis software.	Breathing frequency	The time domain indices RMSSD and SD1 did not differ significantly between SB and CB. However, all frequency domain indices showed significant differences ( $p < 0.05$ ) between SB and CB. Heart rate, SDNN, SD2, LF, TP and LF:HF ratio exhibited significantly higher values ( $p < 0.05$ ) during CB compared to SB. HF was also significantly lower during CB ( $p < 0.05$ ). The time domain indices (RMSSD and SD1) did not seem to be affected by breathing frequency. The researchers therefore concluded that frequency domain HRV indices seem to be significantly affected ( $p < 0.05$ ) by breathing frequency compared to time domain indices that were not affected by breathing frequency.

R-R intervals	Inter-beat intervals or R to R intervals
SDNN	Standard deviation of R-R intervals
RMSSD	Squared root of the mean squared differences between successive R-R intervals
SD1	Standard descriptor 1
SD2	Standard descriptor 2
HF	High frequency power
LF	Low frequency power
LFnu	Low frequency normalised power
TP	Total power
LF:HF ratio	Low and High frequency expressed as a ratio
CB	Controlled breathing
SB	Spontaneous breathing

**Table 2.5 (cont.): Summary of factors that may influence short-term ANS activity in sport and exercise**

Authors and date of publication	Purpose/s of the study	Methodology	Influencing factor	Results and conclusions
Nam <i>et al.</i> (2011)	To determine which posture is appropriate for accurate HRV analysis in 52 healthy individuals (25 males and 27 females).	HRV was taken at 5-minute intervals over a 30-minute session in sitting and recumbent positions. Frequency domain HRV indices were determined through ECG and HRV analysis software.	Posture	The LF:HF ratio in the sitting position showed less significant differences ( $p < 0.001$ ) over the 5-minute intervals during the 30-minute session compared to the recumbent position ( $p < 0.005$ ). The researchers therefore concluded that HRV analysis during the sitting position is more stable when using LF:HF ratio as a HRV measure.
Oliveira <i>et al.</i> (2011)	To assess the influence of water intake on post-exercise autonomic recovery through the analyses of post-exercise HRV in 10 healthy adults (7 males and 3 females).	Subjects were subjected to a 20-minute sub-maximal cycle test. After the cycle test the subjects ingested 500ml of water that was kept at room temperature. HRV was measured (R-R intervals obtained through a polar RS800x heart rate monitor in supine position) before the cycle test and after the water ingestion period. The procedure was also repeated on a separate day with no water ingestion.	Water intake	RMSSD and SDNN showed a significant increase ( $p = 0.05$ ) after water ingestion compared the control (no water ingestion). To conclude, the results suggested that water intake had a positive effect on post-exercise HRV.

R-R intervals

Inter-beat intervals or R to R intervals

SDNN

Standard deviation of R-R intervals

RMSSD

Squared root of the mean squared differences between successive R-R intervals

LF:HF ratio

Low and High frequency expressed as a ratio

**Table 2.5 (cont.): Summary of factors that may influence short-term ANS activity in sport and exercise**

<b>Authors and date of publication</b>	<b>Purpose/s of the study</b>	<b>Methodology</b>	<b>Influencing factors</b>	<b>Results and conclusions</b>
Lima-Silva <i>et al.</i> (2010)	To determine the effects of short-term carbohydrate (CHO) consumption on SNS activity in 12 healthy males. Measurements were repeated 3 times: 1) Once in a high CHO state; 2) Once in a low CHO state and 3) Once in a CHO depleted state (control group).	HRV was taken in the upright position at 5-minute intervals. Time domain and frequency domain HRV indices were analysed by means of R-R intervals (Polar S810i) and Kubios HRV software.	Carbohydrate intake	Normalized HF and LF powers were significantly lower and higher ( $p < 0.05$ ) respectively in the low-CHO diet compared to the control group. LF:HF ratio was higher with the low-CHO diet compared to the control group ( $p < 0.05$ ). The researchers therefore concluded that autonomic cardiac control was influenced by short-term CHO diet.
Blasquez and Ortis (2009)	To compare HRV parameters during the training (TC) and competition period (PC), respectively of 10 master swimmers (6 females, 4 males) to measure autonomic regulation during pre-competitive anxiety situations.	HRV was taken in the supine position 30 minutes prior to TC and PC. Swimmers also completed the competitive state anxiety inventory two (CSAI-2) after their warm-up and HRV was also measured. Time domain and frequency domain HRV indices were analysed through R-R intervals (Polar S810i) and Kubios HRV software.	Pre-competitive anxiety	According to the CSAI-2 results the swimmers exhibited significantly higher anxiety scores ( $p = 0.009$ ) during PC than TC. RMSSD was the only HRV time domain index that showed a significant decrease ( $p = 0.047$ ) during PC. LF:HF ratio and low frequency normalized power (LFnu) showed increases during the PC period ( $p = 0.005$ ). The researchers therefore concluded that RMSSD and LF:HF can be used to evaluate pre-competitive anxiety in swimmers.

HF	High frequency power
LF	Low frequency power
LFnu	Low frequency normalised power
HFnu	High frequency normalized power
TP	Total power
LF:HF ratio	Low and High frequency expressed as a ratio
RMSSD	Squared root of the mean squared differences between successive R-R intervals
CSAI-2	Competitive State Anxiety Inventory-2
CHO	Carbohydrates
TC	Training period
PC	Competition period

**Table 2.5 (cont.): Summary of factors that may influence short-term ANS activity in sport and exercise**

Authors and date of publication	Purpose/s of the study	Methodology	Influencing factors	Results and conclusions
Wiklund <i>et al.</i> (2009)	To investigate the changes in HRV and HRR after completion of a maximal exercise test on a bicycle ergometer while under the influence of: 1. Energy drink (3 cans of Redbull); 2. Mixed energy drink (Redbull with alcohol (0.4 g/kg of vodka) and 3. No stimulants or alcohol. Ten healthy adults (5 males and 5 females) participated in the study.	HRV and HRR were taken directly after exercise for 1 hour while subjects were in the supine position. Frequency domain HRV indices were determined through ECG and HRV analysis software.	Stimulant and alcohol intake	LF:HF ratio was significantly decreased ( $p < 0.05$ ) after 30 minutes of recovery from exercise with the energy drink compared to baseline values (no stimulants and alcohol). HRR was also significantly lower ( $p < 0.05$ ) after ingesting an energy drink with alcohol compared to baseline values. The researchers therefore concluded that cardiac autonomic modulation of subjects is blunted after exercise when ingesting an energy drink mixed with alcohol.

LF:HF ratio

Low and High frequency expressed as a ratio

The results in Table 2.5 suggest that factors such as pre-competition dietary preferences, respiratory status, state of mind and posture may significantly influence ( $p < 0.05$ ) ANS activity and HRV results. The results also indicate that the ANS and related parameters such as HRV are sensitive and can possibly be influenced by a wide range of factors. Differences in breathing frequency (more specifically differences between controlled and spontaneous breathing) can influence HRV significantly due to the increased cognitive demand of controlled breathing which in turn increases sympathetic activity, with frequency domain HRV indices exhibiting significant ( $p < 0.05$ ) changes between controlled and spontaneous breathing in healthy adult male runners (Saboul *et al.*, 2013:538). With regard to differences in posture during HRV measurements, research revealed that a sitting position caused significant ( $p < 0.001$ ) less changes in HRV compared to a recumbent position ( $p < 0.05$ ) in healthy adults (Nam *et al.*, 2011:571). Rehydration status is another factor which significantly influenced HRV, with the ingestion of 500 ml of water after exercise that caused significant changes ( $p = 0.05$ ) compared to no water intake after exercise in healthy adults due to the faster recovery of blood pressure (Oliveira *et al.*, 2011:102). Short-term HRV was also significantly ( $p < 0.05$ ) increased by the amount of carbohydrates ingested before exercise and significantly ( $p < 0.05$ ) decreased by ingesting less carbohydrates before exercise in healthy males (Lima-Silva *et al.*, 2010:546). The ingestion of alcohol before exercise can lead to a significant decrease ( $p < 0.05$ ) in HRV post-exercise. HRR was significantly ( $p < 0.05$ ) decreased (worse) after the ingestion of an alcohol drink before exercise in healthy adults due to the lethargic autonomic recovery caused by cardiac arrhythmia (Wiklund *et al.*, 2009:77). Even pre-competitive anxiety may cause significant changes in HRV with time domain HRV indices that were significantly increased ( $p = 0.047$ ) by an increase in pre-competitive anxiety among master swimmers due to the withdrawal of vagal activity during stressful situations (Blasquez & Ortis, 2009:534).

Other factors (not presented in Table 2.5) may also influence HRV and HRR. In this regard overall HRV and cardiac autonomic responsiveness tends to decrease with age (Acharya *et al.*, 2006:1035). The gender of subjects may also influence HRV and HRR due to the fact that male athletes tend to show faster parasympathetic reactivation and reduced cardiac autonomic responsiveness due to lower a resting sympathetic tone compared to female athletes (Acharya *et al.*, 2006:1035).

From a practical point of view it is imperative that researchers control or correct for as much of these above-mentioned factors as possible when conducting HRV and HRR related studies.

## 2.6 SUMMARY

Despite the potential of HRV and HRR to act as indicators of athletes' fitness levels and the emergence of more affordable and user-friendly apparatuses by which these measurements can be obtained, studies that have investigated these aspects in athletes are scarce. It is against this background that the primary aim of this chapter was to review HRV and HRR as indices to monitor ANS function in exercise and sport settings. In order to fulfil the last-mentioned aim, the following steps were followed: Firstly, the physiology of the ANS was explained in order to provide the reader with a better understanding of the use of HRV and HRR as tools to examine autonomic fluctuations under different physiological conditions. Secondly, methodological aspects of HRV and HRR measurements were discussed and explained. Thirdly, the value of using HRV and HRR in sport and exercise settings was discussed. Finally, limitations of using these parameters in sport and exercise were explained by making use of the available literature.

The chapter therefore started by showing that the ANS entirely or partially control arterial pressure, sweating, body temperature, gastrointestinal motility, gastrointestinal secretion, bladder emptying and many other physiological functions. Literature also indicated that the ANS is divided into the SNS and the PNS which have antagonistic characteristics but function synergistically. The functions of these branches of the ANS differ with the SNS that prepares and sustains the body to face a crisis, danger or stress whereas the PNS is more active when a person is calm and relaxed and little physical demand is put on the body. The end result of the relationship between the SNS and PNS is very effective and responsive regulation of the cardiovascular system. In this regard both HRV and HRR are regarded to be established measures of cardiac autonomic nervous system function and are used in sport and exercise settings. HRV is defined as a measure of the beat-to-beat variation and the time duration between each completed cardiac cycle and HRR as the rate at which heart rate decreases (or time taken for heart rate to recover) after moderate to high intensity exercise.

HRV is usually measured by determining the time that elapses between two R-R cycles and then quantifying these values by analysing it through HRV analysis software in order to obtain HRV parameters for interpretation. Most researchers agree that HRV can be used as a valid physiological parameter of athletes' fitness and performance levels in view of its significant relationship ( $p < 0.05$ ) with psychophysiological status, overreaching status, overtraining, training load, body fat percentage, aerobic performances, anaerobic thresholds, Yo-Yo IR1 performance, maximal aerobic speed and recovery time after exercise in both team and

individual sport participants of different participant levels. However, factors such as the pre-competition dietary preferences, hydration status, respiratory status, mood state and posture of subjects before and during measurement of HRV may significantly influence ( $p < 0.05$ ) the HRV values and lead to measurement errors.

Absolute or relative HRR values are usually obtained by measuring heart rate with a heart rate monitor at cessation of a maximal or sub-maximal exercise and then again post-exercise at a certain time point. The percentage decrease for exercise heart rate to post-exercise heart rate is then calculated. Although research on the use of HRR as a measure of cardiac autonomic nervous system function is not as common as HRV related research, findings show that HRR can be used as a significant indicator ( $p < 0.05$ ) of training program adaptations and effectiveness, overtraining, aerobic performance, physical fitness and recovery for a wide range of individual and team sport participants. HRR can however also be significantly influenced ( $p < 0.05$ ) by ingesting energy drinks and alcohol.

Validated and accurate devices such as a standard ambulatory ECG and Polar heart rate monitors are most commonly incorporated in the protocols of scientific studies to research HRV and HRR. The Actiheart is also a validated device for obtaining a HRV measurement. Other more user-friendly devices used by the sporting fraternity, such as the BioForce and Iathlete Heart Rate Variability Systems, first need to be validated by scientific research to ensure their accurateness in gauging HRV.

Overall, the above-mentioned research results accentuate the importance and value of HRV and HRR as indicators of ANS activity for sport participants and practitioners in the field of sport science. However, HRV and HRR's value for researchers and practitioners will be strengthened if the following recommendations are also considered when implementing these measurements in sport and strength settings:

- ANS should be frequently assessed by means of HRV and HRR before and after exercise to compile a cardiac autonomic profile to which future ANS measurements can be compared.
- HRV can be successfully used as a daily or weekly monitoring tool in order to evaluate the autonomic changes due to physical training. The pattern of HRV changes will allow coaches and sport scientists to make the appropriate program adjustments so that the effectiveness of the training program is ensured.
- HRV and HRR are best used in tandem directly after exercise to evaluate immediate post-exercise responses and to determine the need for recovery.

- Validated and proven methods must be used to measure and analyse HRV and HRR measurements. Devices, such as the Polar heart rate monitor as well as the Actiheart, are suitable devices for obtaining an accurate HRV and HRR measurement. The validity of more user-friendly devices first need to be proven before use in scientific studies that focus on HRV and HRR.

The use of HRV and HRR in sport and exercise is not without its limitations and the following should be considered by future researchers and sport scientists who want to use these measurements in sport and exercise settings:

- The HRV profile of athletes must be obtained before interpreting the HRV results. Sport practitioners will only be able to make accurate evaluations of HRV results by taking a number of baseline measurements to compile a HRV profile.
- HRV measuring and analysis can be complex and time consuming. It is therefore essential that researchers or sport scientists who want to use HRV measurements must be versed in the HRV measuring and analysis techniques.
- In view of the fact that the ANS and ANS related measurements are influenced by various factors, it is crucial to correct for or control these factors so that the repeatability and accuracy of HRV and HRR measurements can be assured.

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## **CHAPTER 3**

### **ARTICLE 1:**

#### **THE USE OF HEART RATE VARIABILITY AND RECOVERY TO DETERMINE THE FITNESS LEVELS OF A COHORT OF UNIVERSITY- LEVEL RUGBY PLAYERS**



**TITLE:** THE USE OF HEART RATE VARIABILITY AND RECOVERY TO DETERMINE THE FITNESS LEVELS OF A COHORT OF UNIVERSITY-LEVEL RUGBY PLAYERS

**RUNNING HEAD:** HEART RATE VARIABILITY AND RECOVERY IN RUGBY PLAYERS

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**THE USE OF HEART RATE VARIABILITY AND RECOVERY TO DETERMINE THE FITNESS LEVELS  
OF A COHORT OF UNIVERSITY-LEVEL RUGBY PLAYERS**

## ABSTRACT

The purpose of this study was to determine if heart rate variability (HRV) and heart rate recovery (HRR) can be used to determine the fitness levels of a cohort of university-level rugby players. Twenty-four university-level rugby players (age  $20.1 \pm 0.41$  years; height  $182.70 \pm 6.20$  cm; weight  $89.70 \pm 12.70$  kg) of a South African University's Rugby Institute participated in the study. During the test day players' fasting baseline HRV (baseline HRV) values were taken. This was followed by the measurement of the post-breakfast HRV (Pre-Yo-Yo IR1 HRV). Players were then required to perform the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1) while they were fitted with a portable gas analyser apparatus (Cosmed K4b<sup>2</sup>) and a Fix Polar Heart Rate Transmitter Belt (Polar team pack, Polar Electro Oy, Kempele, Finland). After completion of the test, HRR was taken on 1 and 3 minutes and followed by the measurement of HRV (Post-Yo-Yo IR1 HRV). Significant correlations ( $p \leq 0.05$ ) were found between Pre-Yo-Yo IR1 HRV and heart rate (HR) at the respiratory compensation point (RCP-HR (bpm)) ( $r = -0.468$ ) as well as oxygen uptake at the RCP ( $\text{RCP-}\dot{V}\text{O}_{2\text{max}}$  (% of  $\dot{V}\text{O}_{2\text{max}}$ )) ( $r = 0.476$ ), respectively. A forward stepwise regression analysis showed that HR at ventilatory threshold 1 (VT1-HR (bpm)) contributed significantly ( $p \leq 0.05$ ) to the post-Yo-Yo IR1 HRV with a variance of 39.8%. The final Yo-Yo IR1 level also contributed significantly ( $p \leq 0.05$ ) to the 3 minute post-Yo-Yo IR1 heart rate recovery (HRR) with a variance of 16.5%. In conclusion, HRV and HRR may have the potential to act as affordable and easy measurement tools of team sport participants' fitness levels.

**KEY WORDS:** BioForce Heart Rate Variability system, Yo-Yo Intermittent Recovery Test 1, autonomic nervous system.

## INTRODUCTION

The clinical use of heart rate variability (HRV) to evaluate overall health status in the general population, has led exercise physiologists and coaches to investigate the use, applicability and suitability of this parameter to analyse and evaluate different aspects in the physiological make-up of sport participants (13,21). HRV can be defined as a measure of the beat-to-beat variation and the time duration between each completed cardiac cycle (heart beat) (29). HRV also reflects the modulation of cardiac function by the autonomic nervous system (ANS) and other physiological regulatory systems (37). Another technique to measure the responsiveness of the ANS is the measurement of heart rate recovery (HRR) (9,31). HRR is the rate at which heart rate (HR) decreases (or time taken for HR to recover) after moderate to heavy exercise and is dependent on the balance between parasympathetic and sympathetic nervous system activity (5). According to Makivic et al. (37), the cardiovascular system is constantly being regulated by autonomic activity to ensure optimal efficiency of cardiac functions, and HRV as well as HRR may be useful tools to examine autonomic fluctuations under different physiological conditions such as training. Researchers have been compelled to consider the suitability and accuracy of HRV and HRR to determine the physical fitness levels of athletes (21) in view of certain constraints that are related to the direct measurement of physical fitness (maximal aerobic power), such as: the need for specialised, sophisticated equipment which is very expensive; the need for well-trained personnel to operate the equipment (15), the time inefficiency of these kind of tests and the impracticality of the tests to measure large groups of athletes, such as rugby teams (33). However, despite the potential of HRV and HRR to provide people in the sporting fraternity with an affordable and easy measurement tool of team sport participants' fitness levels, studies that have investigated this aspect in the last-mentioned population are scarce and contradictory.

Cardiorespiratory endurance or maximal aerobic power is one of the main indicators of physical fitness (12) and is accurately determined by the direct measurement of  $\dot{V}O_{2\max}$  (maximal oxygen uptake) by indirect calorimetry and specifically by open-circuit spirometry during a graded maximal test in the laboratory (12). Previous studies have demonstrated that  $\dot{V}O_{2\max}$  and sub-maximal, physiological parameters such as the first ventilatory threshold (VT1) and the respiratory compensation point (RCP), that can all be obtained from the graded maximal test and gas analysis, are very good indicators of maximal aerobic power or endurance performance (16). Researchers who have investigated the possible relationship between HRV and sub-maximal,

physiological parameters in cyclists, tri-athletes and normal healthy adult subjects determined that VT1, lactate threshold (LT) and the second ventilatory threshold (VT2) which usually correspond to the RCP, could be effectively identified by closely monitoring vagal modulation during exercise (16,29). In this regard Karapetian et al. (29) established a significant correlation of  $r = 0.89$  ( $p < 0.05$ ) between HRV-based and actual VT2 as well as between HRV-based and actual LT ( $r = 0.82$ ,  $p < 0.05$ ) in normal healthy adults. Similarly, Cottin et al. (16) found a significant correlation between peak high frequency stimulation (point where high frequency band exhibits the highest spectral energy during a spectral analysis of HRV indices) and VT1 ( $r = 0.92$ ,  $p < 0.001$ ) as well as between the first mentioned variable and VT2 ( $r = 0.98$ ,  $p < 0.001$ ) in well trained competitive cyclists and tri-athletes. Martinmaki et al. (38) monitored HRV changes in healthy adult subjects during sub-maximal exercise and observed that the increases in all HRV indices corresponded to an increase in  $\dot{V}O_{2\text{peak}}$  during exercise. They also concluded that training led to more responsive autonomic control during exercise which corresponded to an increase in  $\dot{V}O_{2\text{peak}}$  (41). An exploratory study by Hedelin et al. (26) reported a significant negative correlation between low frequency-variability (the change in normalized low frequency power output) and  $\dot{V}O_{2\text{max}}$  ( $r = -0.56$ ,  $p < 0.001$ ) in competitive skiers and canoeists.

Only a few researchers have investigated the HRV indices of team sport participants. A study by Ke-tiem et al. (30) investigated the influence of an eight-week cardio-respiratory endurance training program on HRV and  $\dot{V}O_{2\text{max}}$  of 24 male rugby players. They observed that the cardio-respiratory endurance training program led to significant increases ( $p < 0.05$ ) in the HF and LF:HF ratio (30). Another study revealed that SDNN (standard deviation of R-R intervals and a reflection of global variability) and SD2 (standard descriptor 2 and a representation of long-term variability) correlated significantly with Yo-Yo Intermittent Recovery Test 1 (Yo-Yo IR1) performance ( $r = 0.89$ ,  $p = 0.07$  and  $r = 0.92$ ,  $p = 0.03$ ) in male elite soccer players after an eight-week pre-season training period (7). The last-mentioned studies therefore all suggest that HRV can possibly serve as an indicator of training status and fitness level changes in team sport participants. However, in contrast to this conclusion Oliveira et al. (2012) reported that no HRV indices were significantly related to any Yo-Yo IR1 performance variables during any time period of the Futsal season. HRV indices also did not improve after the initial 3 weeks of pre-season training in 11 Futsal players (40). Despite these results the authors stated that frequent

monitoring of HRV indices can assist with the identification of individual training adaptation (40).

Studies that have investigated the application of HRR to assess and predict fitness levels of well-trained endurance and strength-trained athletes, observed a faster than normal HRR after completion of maximal exhaustive exercise (31). Furthermore, Lamberts et al. (31) succeeded in showing a strong relationship between improved HRR and improved cycling performance ( $r = 0.96$ ,  $p < 0.0001$ ) in a group of well-trained cyclists after a 4 week high intensity training period. Moreover, a more recent study by Lee and Mendoza (32) found significant relationships between HRR and  $\dot{V}O_{2\max}$  ( $r = 0.51$ ,  $p < 0.05$ ) as well as physical activity ( $r = 0.67$ ,  $p < 0.05$ ) in well-trained athletes after being subjected to a maximal graded exercise test. In contrast to the above-mentioned results Bosquet et al. (6) found no significant correlations between HRV, HRR and  $\dot{V}O_{2\max}$  in physically active adults. Similarly, Esco et al. (20) also did not observe any significant relationships between  $\dot{V}O_{2\max}$ , resting HRV and post-exercise HRR in healthy college students. These researchers did, however, conclude that subjects with higher aerobic fitness levels displayed better HRV and HRR profiles and yielded a better relationship between the last-mentioned variables and  $\dot{V}O_{2\max}$  than normal, healthy, adult subjects (20).

In view of the last-mentioned findings and the fact that team sports such as rugby requires a complex combination of both cardiorespiratory and neuromuscular fitness, the potential of HRR and HRV to predict changes in both aerobic fitness and neuromuscular performance should be considered and investigated (10,17). Also, despite the potential of HRV and HRR to act as indicators of team sport participants' fitness levels and the emergence of a more affordable and user-friendly apparatus (BioForce Heart Rate Variability System and the Polar Team<sup>2</sup> Pro Electro system) by which these measurements can be obtained, studies that have investigated these aspects in team sport participants are scarce and contradictory. It is against this background, that the purpose of this study was to determine the relationships between HRV and HRR as well as the fitness levels of a cohort of university-level rugby players. Results of this study may possibly provide coaches and sport related professionals with information regarding the accuracy and usefulness of HRV and HRR as indicators of fitness levels in university-level rugby players.

## **METHODS**

### **Experimental Approach to the Problem**

The specific hypothesis under scrutiny was that significant relationships will exist between HRV and HRR as well as the fitness levels of a cohort of university-level rugby players. This hypothesis was tested by making use of an experimental research design, with convenience sampling. During the test day players' fasting baseline HRV (baseline HRV) values were taken. This was followed by the measurement of the post-breakfast HRV (Pre-Yo-Yo IR1 HRV). Players were then required to perform the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1) while they were fitted with a portable gas analyser apparatus (Cosmed K4b<sup>2</sup>, Cosmed Ltd., Rome, Italy) and a Fix Polar Heart Rate Transmitter Belt (Polar Electro, Kempele, Finland). After completion of the test, HRR was taken on 1 and 3 minutes and followed by the measurement of HRV (Post-Yo-Yo IR1 HRV).

### **Subjects**

A group of twenty-eight u/21 university-level rugby players ( $20.10 \pm 0.41$  years) of a South African University's Rugby Institute were recruited to participate in this study. Only rugby players who were actively involved and training as members of the Rugby Institute as well as those who were totally injury free at the time of testing were eligible to participate in the study. Four players were injured before the start of the study and had to be excluded from the subject group which meant that only twenty-four players participated in the study. The anthropometric characteristics of the subjects who participated in the study are presented in Table 1. The competitive rugby playing experience of these players varied between 4 and 15 years with an average of  $10.20 \pm 2.80$  years. Regarding position, the group consisted of 12 backs (numbered nine to fifteen) and 12 forwards (numbered one to eight). The study design, purpose and possible risks of the study were explained to the subjects, and written informed consent was obtained from the subjects before the investigation. Subjects also completed a general information questionnaire regarding their ages, exercising habits, injury incidents, competing levels and best performances. Approval for the research was granted by the Ethics Committee of the institution where the research was conducted.

**TABLE 1.** Anthropometric characteristics of subjects\*

Parameters	Subjects ( $n = 24$ )	Range
Body stature (cm)	$182.70 \pm 6.20$	169.95-195.30
Body mass (kg)	$89.70 \pm 12.70$	60.30-122.10
Body fat percentage (%)	$11.90 \pm 3.80$	6.80-20.00
Muscle mass (kg)	$37.54 \pm 18.14$	28.60-90.40
Muscle mass percentage (%)	$40.30 \pm 13.95$	23.51-74.04
Skeletal mass (kg)	$9.94 \pm 1.19$	8.04-12.41
Skeletal mass percentage (%)	$11.18 \pm 1.15$	8.60-13.33

\*Values are mean  $\pm$ SD.

Each subject was instructed to sleep at least 8 hours during the evening and morning prior to the testing session. They also had to abstain from ingesting any drugs or participating in strenuous physical activity that may influence the physical or physiological responses of the body for at least 48 hours before the scheduled test. Subjects had to maintain the same diet during the week of testing. The subjects arrived at the testing sessions in a rested and fully hydrated state. The players were tested during the in-season phase of their periodization cycle. During the in-season phase the players spent an average of  $1.8 \pm 0.70$  hours a day on weight training for  $3.50 \pm 0.90$  days per week. They also spent an average of  $2.4 \pm 1.20$  hours a day on field training sessions for  $3.9 \pm 0.70$  days per week. During the time of testing they already completed three months of a combined rugby conditioning program which consisted of field training sessions five times a week and resistance training sessions four times a week. The field training sessions were focused on rugby specific drills, skills and activities that were aimed at improving the players' fitness levels. The gym resistance training sessions focused on improving players' functional muscle strength and explosive power.

### Testing Procedures

Several days before the commencement of the research project the players were informed of the nature of the study, and all potential risks and benefits were explained to them. During this session informed consent for the investigation was also requested from the players and a demographic and general information questionnaire completed. The rugby players underwent one day of testing. During the testing day the players reported at the laboratory early in the morning so that baseline values could be taken. The baseline testing took place in a fasting state within ten to twenty minutes after players had woken up in view of the fact that they had travel on their own from their places of residence to the laboratory. A Fix Polar Heart Rate Transmitter

Belt was strapped to the chest of each player. Next, the measurement of HRV (baseline HRV) took place. Players then had a chance to eat breakfast at their own places of residence after which they again reported to the laboratory, one player at a time, on the same day so that the anthropometric measurements could be taken and the HRV measurement (Pre-Yo-Yo IR1 HRV) repeated. After completion of the measurements, players were subjected to the Yo-Yo IR1 while they were fitted with a portable gas analyser apparatus. Exactly 1 and 3 minutes after the cessation of the Yo-Yo IR1 the HR values at each of these time periods were taken. This was followed by the measurement of HRV (Post-Yo-Yo IR1 HRV) while the players were lying down.

*Anthropometric measurements:* The anthropometric components were determined in accordance with the protocols of The International Society for the Advancement of Kinanthropometry (ISAK) (44). Anthropometric measurements were taken to describe the specific cohort of rugby players with regard to their anthropometric characteristics. The body mass was recorded to the nearest 0.1 kg, using a calibrated BFW 300 Platform scale (Adam equipment Co. Ltd., U.K.) and the body stature to the nearest 0.1 cm, using a Harpenden portable stadiometer (Holtain Ltd., U.K.). Body fat, muscle and skeletal mass were also analysed under this section. Body fat was determined through the sum of the following skinfolds (SUM6SF): triceps, subscapular, abdominal, supraspinal, front thigh and calf skinfolds; according to the formulas of Withers et al. (47). The skinfolds were taken with a Harpenden skinfold calliper (Holtain Ltd., U.K.) with a constant pressure of  $10 \text{ g}\cdot\text{mm}^{-2}$  to the nearest 0.2 mm. Muscle and skeletal mass were calculated using the formulas as cited by Lee et al. (34) as well as Drinkwater and Mazza (19) respectively. The following anthropometric variables were measured under the section of muscle and skeletal mass: body stature and mass; relaxed arm, thigh and calf girth; triceps, thigh and calf skinfolds as well as ankle, femur, humerus and wrist breadths. The girth measurements were taken with a Lufkin metal tape (Cooper Industries, U.S.A.) to the nearest 0.1 cm while the breath measurements were taken with a Holtain Bicondylar calliper (Holtain Ltd., U.K.) to the nearest 0.1 mm. After land-marking each test subject, measurements were performed twice by three Level 2 ISAK certified anthropometrists. The technical error of measurement (TEM) was calculated by making use of the formula of Pederson and Gore (41) and revealed values of 6.77% (0.70 mm) for all skinfold measurements, 4.15% (0.29 cm) for all breadth measurements and 1.17% (0.47 cm) for all girth measurements.

*Yo-Yo IR1*: The players performed the Yo-Yo IR1 in their rugby boots on a rugby field. According to Bangsbo et al. (3), the Yo-Yo IR1 test is the most extensively studied fitness test in sports science because of the specificity and practicality of the test. Furthermore, the Yo-Yo IR1 has been widely applied in many team sports to evaluate players' abilities to repeatedly perform high-intensity exercise (3). The Yo-Yo IR1 is a validated exercise test that ensures that subjects reach their  $\dot{V}O_{2max}$ , with a significant correlation established between  $\dot{V}O_{2max}$  and Yo-Yo IR1 results ( $r = 0.70, p < 0.05$ ) (3).

On arrival the test procedure was clearly explained to each player. However, all of the players that were tested have been subjected to the Yo-Yo IR1 before. Players were required to run back and forth on the 20 m track and pace themselves so that the arrival at the end of the 20 m stretch coincided with the signal that was emitted from a commercially available pre-recorded compact disc (2). The players had to touch the marked lines at either end of the 20m stretch with one foot as the signal sounded from the CD. Each player received a short 10 seconds active break after each 40 m (2 x 20 m runs) during which they walked back and forth over a 5 m stretch (they thus walked a total of 10 m back to starting line). The test started at a speed of  $10 \text{ km}\cdot\text{h}^{-1}$  after which the speed increased until the test was terminated due to players that voluntarily dropped out or could not make it to either end marks of the 20 m distance within the given signal time in two successive shuttles. The results noted were the distances covered at the points where the players could not maintain the speed of the test. The players were verbally encouraged to perform maximally during each assessment.

$\dot{V}O_{2max}$  and sub-maximal, physiological parameters: Each player ran the Yo-Yo IR1 while fitted with a portable gas analyser apparatus and a Fix Polar Heart Rate Transmitter Belt, which were used to sample expired air continuously and the rate of oxygen consumption ( $\dot{V}O_2$ ), carbon dioxide production ( $\dot{V}CO_2$ ), minute ventilation ( $\dot{V}_E$ ), respiratory exchange ratio (RER) as well as the HR for each 5-second period. The portable gas analyser was calibrated with standard gases before commencement of the test. The  $\dot{V}O_{2max}$  value of each player was also determined by using the following criteria for the attainment of  $\dot{V}O_{2max}$ : a RER-value of higher than 1.15; an oxygen consumption that 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 (18,39).

Two physiological gas exchange points were also identified through the data that was sampled by the portable gas analyser apparatus during execution of the Yo-Yo IR1. The VT1 was determined using the criteria of an increase in  $\dot{V}_E/\dot{V}O_2$  with no increase in  $\dot{V}_E/\dot{V}CO_2$  and departure from the linearity of  $\dot{V}_E$  (14). The VT1 is the point where pulmonary ventilation increases in response to the rise in  $CO_2$  from lactate buffering, with regulation of the arterial partial pressure of  $CO_2$  (14). The RCP was taken as the point which corresponds to an increase in both  $\dot{V}_E/\dot{V}O_2$  and  $\dot{V}_E/\dot{V}CO_2$  (14). At RCP the respiratory compensation from metabolic acidosis with lowering of the arterial partial pressure of  $CO_2$  occurs. VT1 and RCP were visually detected by two independent experienced researchers. Higher VT1 and RCP, expressed as a percentage of  $\dot{V}O_{2max}$ , are a reflection of a better capacity to produce energy or power aerobically (23,36).

*Heart rate variability:* HRV was measured with the BioForce Heart Rate Variability System (Performance Sport Inc., Washington, USA) using a Fix Polar Heart Rate Transmitter Belt as well as a wireless receiver and software that was downloaded on an iPad. According to the manufacturers' web site, the HRV values that were obtained from this system correlated well with the Omegawave Sport Technology System (Omegawave, Portland, Oregon, USA) (27). Due to the fact that Berkoff et al. (4) alluded to the fact that the Omegawave device complies with all guidelines recommended by the task force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology Standards for Measurement of Heart Rate Variability, this device can be regarded as a valid apparatus to measure HRV (42).

Each player was requested to lie still on his back for a period of more or less 3 minutes so that the HRV could be determined. The HRV value as well as the time on which the HRV value were taken, were noted. The Bioforce Heart Rate Variability System displays a HRV which can be categorised as follows: 0-60 = low HRV; 60-70 = fair HRV, 70-80 = moderate HRV, 80-90 = high HRV and >90 = very high HRV (28).

*Heart rate recovery:* A Fix Polar Heart Rate Transmitter Belt was used to measure HR on 1 and 3 minutes directly after cessation of the Yo-Yo IR1. The HRR was then calculated by calculating the percentage decline from the maximal Yo-Yo IR1 test obtained HR to the HR values that were noted on 1 and 3 minutes after cessation of the test.

## **Statistical analysis**

The Statistical Data Processing package (43) was used to process the data. Firstly, the descriptive statistics (averages, standard deviations, minimum and maximum values) of each of the testing variables were calculated. Next, Pearson Product-moment Correlation Coefficients between the baseline and Pre-Yo-Yo IR1 HRV related values were determined. The results of the last-mentioned analysis were used to determine if the intake of food had any influence on the HRV values. Thirdly, a cluster analysis of the different Yo-Yo IR1 related variables was performed in order to detect clusters of variables that are related to each other. The linkage distance for the detection of different clusters was set at 60 by the researchers. This was followed by the calculation of the Pearson Product-moment Correlation Coefficients to determine the relationships between the baseline, Pre-Yo-Yo IR1 HRV and cluster analysis reduced Yo-Yo IR1 related variables, respectively. Lastly, two sets of forward stepwise multiple regression analyses were performed. In the first forward stepwise multiple regression analysis the post-Yo-Yo IR1 derived HRV was categorised as the dependent variable, whereas the cluster analysis reduced Yo-Yo IR1 derived variables were categorised as the independent variables. In the second set of forward stepwise multiple regression analyses the post-Yo-Yo IR1 derived HRR at 1 and 3 minutes, respectively was categorised as the dependent variables, whereas the cluster analysis reduced Yo-Yo IR1 derived variables were categorised as the independent variables. The level of significance for all analyses was set at  $p \leq 0.05$ .

## **RESULTS**

### **HRV and HRR related variables**

Results of the descriptive statistics for the baseline, pre- and post-Yo-Yo IR1 HRV and post-Yo-Yo IR1 HRR measurements are presented in Table 2.

**TABLE 2.** Descriptive statistics of the HRV and HRR related measurements\*

HRV and HRR related measurements	Subjects ( $n = 24$ )	Range
Baseline HRV	$88.50 \pm 12.22$	59.00-108.00
Pre-Yo-Yo IR1 HRV	$79.00 \pm 9.70$	63.00-101.00
Post-Yo-Yo IR1 HRV	$28.20 \pm 14.20$	10.00-70.00
1 min Post-Yo-Yo IR1 HR (bpm)	$154.00 \pm 11.26$	130.00-177.00
1 min Post-Yo-Yo IR1 HRR (%)	$16.99 \pm 4.83$	11.50-26.14
3 min Post-Yo-Yo IR1 HR (bpm)	$117.45 \pm 8.84$	105.00-130.00
3 min Post-Yo-Yo IR1 HRR (%)	$36.64 \pm 4.62$	27.78-43.62

\*Values are mean  $\pm$  SD. Baseline HRV = Fasting heart rate variability value; Pre-Yo-Yo IR1 HRV = Pre-Yo-Yo Intermittent Recovery Test heart rate variability value; Post-Yo-Yo IR1 HRV = Post-Yo-Yo Intermittent Recovery Test heart rate variability value; 1 min Post-Yo-Yo IR1 HR (bpm) = heart rate in beats per minute 1 minute after completion of the Yo-Yo Intermittent Recovery test; 1 min Post-Yo-Yo IR1 HRR (%) = 1 minute heart rate recovery after completion of the Yo-Yo Intermittent Recovery test as a percentage; 3 min Post-Yo-Yo IR1 HR (bpm) = heart rate in beats per minute 3 minutes after completion of the Yo-Yo Intermittent Recovery test; 3 min Post-Yo-Yo IR1 HRR (%) = 3 minute heart rate recovery after completion of the Yo-Yo Intermittent Recovery test as a percentage.

From the results in Table 2 it is clear that the average HRV obtained for the early morning measurement before breakfast was 88.5 while the HRV before execution of the Yo-Yo IR1 (pre-Yo-Yo IR1 HRV) was 79 compared to an average value of 28.2 that was obtained after completion of the Yo-Yo IR1 (post-Yo-Yo IR1 HRV). Furthermore, the HRR-values suggest that the players' HR decreased on average by 16.99% and 36.64 % during 1 and 3 minutes post-Yo-Yo IR1, respectively.

### Yo-Yo IR1 aerobic fitness related variables

According to the results in Table 3 the players achieved an average  $\dot{V}O_{2\max}$  value of 46.32 ml·kg<sup>-1</sup>·min<sup>-1</sup> with an average maximal HR ( $HR_{\max}$ ) value of 185.5 bpm during the execution of the Yo-Yo IR1. The highest average level that was reached in the Yo-Yo IR1 was 16.15. VT1 occurred at a Yo-Yo IR1 level of 11.25 at an average HR of 143.62 bpm, which was calculated to be 77.55% of the  $HR_{\max}$  and 84.26% of the  $\dot{V}O_{2\max}$ . Furthermore, the RCP occurred at a Yo-Yo IR1 level of 13.33 at an average HR of 168.12 bpm which is 90.78% of the  $HR_{\max}$  and 95.56% of the  $\dot{V}O_{2\max}$ .

**TABLE 3.** Descriptive statistics of the Yo-Yo IR1 aerobic fitness related variables\*

Yo-Yo IR1 aerobic fitness related variables	Subjects ( $n = 24$ )	Range
VT1- $\dot{V}_E$ ( $L \cdot \text{min}^{-1}$ )	$100.08 \pm 13.55$	79.87-137.12
VT1-HR (bpm)	$143.62 \pm 15.73$	100.00-168.00
VT1-Yo-Yo IR1 level	$11.25 \pm 0.53$	11.00-13.00
VT1- $\dot{V}O_2$ ( $L \cdot \text{min}^{-1}$ )	$39.02 \pm 5.64$	27.61-55.98
VT1-HR (% of $HR_{\text{max}}$ )	$77.55 \pm 8.09$	53.19-89.73
VT1- $\dot{V}O_{2\text{max}}$ (% of $\dot{V}O_{2\text{max}}$ )	$84.26 \pm 6.19$	78.84-100.00
RCP- $\dot{V}_E$ ( $L \cdot \text{min}^{-1}$ )	$130.21 \pm 11.60$	110.37-147.51
RCP-HR (bpm)	$168.12 \pm 7.40$	154.00-186.00
RCP-Yo-Yo IR1 level	$13.33 \pm 0.91$	12.00-16.00
RCP- $\dot{V}O_2$ ( $L \cdot \text{min}^{-1}$ )	$44.28 \pm 5.73$	32.65-53.91
RCP-HR (% of $HR_{\text{max}}$ )	$90.78 \pm 2.85$	84.18-96.76
RCP- $\dot{V}O_{2\text{max}}$ (% of $\dot{V}O_{2\text{max}}$ )	$95.56 \pm 3.22$	85.93-100.00
Final Yo-Yo IR1 level	$16.15 \pm 1.22$	14.10-19.60
Yo-Yo IR1 $HR_{\text{max}}$ (bpm)	$185.50 \pm 7.27$	173.00-200.00
Yo-Yo IR1 $\dot{V}O_{2\text{max}}$ ( $\text{ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ )	$46.32 \pm 5.75$	34.62-57.50

\*Values are mean  $\pm$  SD. VT1- $\dot{V}_E$  ( $L \cdot \text{min}^{-1}$ ) = minute ventilation in liters per minute at ventilatory threshold one; VT1- HR (bpm) = heart rate in beats per minute at ventilatory threshold one; VT1-Yo-Yo IR1 level = Yo-Yo Intermittent Recovery Test level at ventilatory threshold one; VT1- $\dot{V}O_2$  ( $L \cdot \text{min}^{-1}$ ) = oxygen uptake in liters per minute at ventilatory threshold one; VT1- HR (% of  $HR_{\text{max}}$ ) = heart rate in percentage of maximal heart rate at ventilatory threshold one; VT1- $\dot{V}O_{2\text{max}}$  (% of  $\dot{V}O_{2\text{max}}$ ) = oxygen uptake as percentage of maximal oxygen uptake at ventilatory threshold one; RCP- $\dot{V}_E$  ( $L \cdot \text{min}^{-1}$ ) = minute ventilation in liters per minute at respiratory compensation point; RCP- HR (bpm) = heart rate in beats per minute at respiratory compensation point; RCP-Yo-Yo IR1 level = Yo-Yo Intermittent Recovery Test level at respiratory compensation point; RCP- $\dot{V}O_2$  ( $L \cdot \text{min}^{-1}$ ) = oxygen uptake in liters per minute at respiratory compensation point; RCP- HR (% of  $HR_{\text{max}}$ ) = heart rate in percentage of maximal heart rate at respiratory compensation point; RCP- $\dot{V}O_{2\text{max}}$  (% of  $\dot{V}O_{2\text{max}}$ ) = oxygen uptake as percentage of maximal oxygen uptake at respiratory compensation point; Final Yo-Yo IR1 level = final Yo-Yo Intermittent Recovery Test level obtained; Yo-Yo IR1  $HR_{\text{max}}$  (bpm) = maximal heart rate obtained during Yo-Yo Intermittent Recovery Test; Yo-Yo IR1  $\dot{V}O_{2\text{max}}$  ( $\text{ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ ) = maximal oxygen uptake in milliliters per minute per kilograms body mass obtained during Yo-Yo Intermittent Recovery Test.

### Relationship between baseline and Pre-Yo-Yo IR1 HRV

A correlation coefficient of  $r = 36$  ( $p = 0.08$ ) was found between the baseline and Pre-Yo-Yo IR1 HRV values of the players. Due to the fact that a non-significant correlation coefficient was found between the baseline and Pre-Yo-Yo IR1 HRV values, the researchers were compelled to also determine the relationship between the baseline HRV and cluster analysis reduced Yo-Yo IR1 related variables.

In a subsequent step a cluster analysis was performed and reduced the number of variables from 14 to 7. The variables that remained after completion of the cluster analysis, were: VT1- $\dot{V}_E$  ( $L \cdot \text{min}^{-1}$ ); RCP- $\dot{V}_E$  ( $L \cdot \text{min}^{-1}$ ); RCP-HR (bpm); VT1-HR (bpm); Yo-Yo IR1  $\dot{V}O_{2\text{max}}$  ( $\text{ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ ); RCP- $\dot{V}O_{2\text{max}}$  (% of  $\dot{V}O_{2\text{max}}$ ) and Final Yo-Yo IR1 level.

### Relationships between baseline HRV and the Yo-Yo IR1 aerobic fitness related variables

The Pearson Correlation Coefficient results of the relationships between the baseline HRV and the Yo-Yo IR1 aerobic fitness related variables are presented in Table 4.

**TABLE 4.** Results of the Pearson Correlation Coefficients of the relationships between the baseline HRV and the Yo-Yo IR1 aerobic fitness related variables

Yo-Yo IR1 aerobic fitness related variables	Baseline HRV
VT1- $\dot{V}_E$ ( $L \cdot \text{min}^{-1}$ )	-0.124
RCP- $\dot{V}_E$ ( $L \cdot \text{min}^{-1}$ )	-0.048
RCP-HR (bpm)	-0.042
VT1-HR (bpm)	-0.285
RCP- $\dot{V}O_{2\text{max}}$ (% of $\dot{V}O_{2\text{max}}$ )	0.060
Yo-Yo IR1 $\dot{V}O_{2\text{max}}$ ( $\text{ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ )	0.060
Final Yo-Yo IR1 level	0.235

\*Significant at  $p < 0.05$ ; VT1- $\dot{V}_E$  ( $L \cdot \text{min}^{-1}$ ) = ventilatory equivalent in liters per minute at ventilatory threshold one; RCP- $\dot{V}_E$  ( $L \cdot \text{min}^{-1}$ ) = ventilatory equivalent in liters per minute at respiratory compensation point; RCP- HR (bpm) = heart rate in beats per minute at respiratory compensation point; VT1- HR (bpm) = heart rate in beats per minute at ventilatory threshold one; RCP- $\dot{V}O_{2\text{max}}$  (% of  $\dot{V}O_{2\text{max}}$ ) = oxygen uptake as percentage of maximal oxygen uptake at respiratory compensation point; Yo-Yo IR1  $\dot{V}O_{2\text{max}}$  ( $\text{ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ ) = maximal oxygen uptake in milliliters per minute per kilograms body mass obtained during ; Yo-Yo Intermittent Recovery Test; Final Yo-Yo IR1 level = final Yo-Yo intermittent recovery test level obtained.

Table 4 shows that the correlations between the baseline HRV and the Yo-Yo IR1 aerobic fitness related variables yielded non-significant results.

### Relationships between Pre-Yo-Yo IR1 HRV and the Yo-Yo IR1 aerobic fitness related variables

The Pearson Correlation Coefficient results of the relationships between the pre-Yo-Yo IR1 HRV and the Yo-Yo IR1 aerobic fitness related variables are presented in Table 5.

**TABLE 5.** Results of the Pearson Correlation Coefficients of the relationships between the pre-Yo-Yo IR1 HRV and the Yo-Yo IR1 aerobic fitness related variables

Yo-Yo IR1 aerobic fitness related variables	Pre-Yo-Yo IR1 HRV
VT1- $\dot{V}_E$ (L·min <sup>-1</sup> )	-0.325
RCP- $\dot{V}_E$ (L·min <sup>-1</sup> )	-0.048
RCP-HR (bpm)	-0.468*
VT1-HR (bpm)	-0.367
RCP- $\dot{V}O_{2max}$ (% of $\dot{V}O_{2max}$ )	0.476*
Yo-Yo IR1 $\dot{V}O_{2max}$ (ml·min <sup>-1</sup> ·kg <sup>-1</sup> )	-0.123
Final Yo-Yo IR1 level	-0.143

\*Significant at  $p < 0.05$ ; VT1- $\dot{V}_E$  (L·min<sup>-1</sup>) = ventilatory equivalent in liters per minute at ventilatory threshold one; RCP- $\dot{V}_E$  (L·min<sup>-1</sup>) = ventilatory equivalent in liters per minute at respiratory compensation point; RCP- HR (bpm) = heart rate in beats per minute at respiratory compensation point; VT1- HR (bpm) = heart rate in beats per minute at ventilatory threshold one; RCP-  $\dot{V}O_{2max}$  (% of  $\dot{V}O_{2max}$ ) = oxygen uptake as percentage of maximal oxygen uptake at respiratory compensation point; Yo-Yo IR1  $\dot{V}O_{2max}$  (ml·min<sup>-1</sup>·kg<sup>-1</sup>) = maximal oxygen uptake in milliliters per minute per kilograms body mass obtained during ; Yo-Yo Intermittent Recovery Test; Final Yo-Yo IR1 level = final Yo-Yo intermittent recovery test level obtained.

The results in Table 5 show that only the relationships between pre-test HRV and RCP-HR (bpm) as well as RCP- $\dot{V}O_{2max}$  (% of  $\dot{V}O_{2max}$ ) obtained significant correlations of -0.468 and 0.476 ( $p \leq 0.05$ ), respectively.

### Relationships between the Yo-Yo IR1 aerobic fitness related variables and the post-Yo-Yo IR1 HRV

Table 6 contains the results of the forward stepwise multiple regression analysis between the Yo-Yo IR1 aerobic fitness related variables and the post-test HRV.

**TABLE 6.** Results of the forward stepwise multiple regression analysis between the Yo-Yo IR1 aerobic fitness related variables and the post-Yo-Yo IR1 HRV

Yo-Yo IR1 aerobic fitness related variables	<i>F</i> -value	Multiple <i>R</i>	<i>R</i> -square	<i>R</i> -square change	<i>p</i> -value
VT1-HR (bpm)	14.589	0.631	0.398	0.398	0.0009*
RCP-HR (bpm)	2.287	0.676	0.457	0.059	0.145
RCP- $\dot{V}_E$ (L·min <sup>-1</sup> )	1.073	0.696	0.485	0.027	0.312

\* Significant at  $p < 0.05$ ; *R* = coefficient of multiple correlation; *R*-square = coefficient of multiple correlation squared; VT1- HR (bpm) = heart rate in beats per minute at ventilatory threshold one; RCP- HR (bpm) = heart rate in beats per minute at respiratory compensation point; RCP- $\dot{V}_E$  (L·min<sup>-1</sup>) = ventilatory equivalent in liters per minute at respiratory compensation point.

The forward stepwise multiple regression results revealed that only VT1-HR (bpm) contributed significantly ( $p \leq 0.05$ ) to the post-Yo-Yo IR1 HRV. From the results it is also clear that VT1-HR (bpm) was the biggest contributor to post-Yo-Yo IR1 HRV with more or less 39.8% of the variance in post-test HRV results that could be explained by this aerobic fitness related variable. The rest of the multiple regression analysis identified Yo-Yo IR1 aerobic fitness related variables (RCP-HR (bpm) and RCP- $\dot{V}_E$  (L·min<sup>-1</sup>)) collectively contributed 8.6% to the variance in post-Yo-Yo IR1 HRV results. However, the contributions of these variables were non-significant. The overall stepwise regression analysis correlation coefficient ( $R^2 = 0.4854$ ) indicates that the above-mentioned variables were responsible for 48.54% of the variance in post-Yo-Yo IR1 HRV results. This would mean that variables other than the variables in this study contributed 51.46% to the variance in the post-Yo-Yo IR1 HRV results among the players.

### **Relationships between the Yo-Yo IR1 aerobic fitness related variables and the post-Yo-Yo IR1 HRR measurements (%)**

Table 7 presents the results of the forward stepwise multiple regression analysis between the Yo-Yo IR1 aerobic fitness related variables and the 1 minute post-Yo-Yo IR1 HRR measurements.

The forward stepwise multiple regression analysis results show that none of the Yo-Yo IR1 aerobic fitness related variables served as significant predictors of 1 minute post-Yo-Yo IR1 HRR. However, the stepwise regression analysis correlation coefficient reveals that 30.9% ( $R^2 = 0.309$ ) of the variance in 1 minute post-Yo-Yo IR1 HRR measurements could be explained by Yo-Yo IR1  $\dot{V}O_{2max}$  (ml·min<sup>-1</sup>·kg<sup>-1</sup>), RCP-HR (bpm) and RCP- $\dot{V}O_{2max}$  (% of  $\dot{V}O_{2max}$ ). The last-mentioned variables contributed 15.9%, 10.9% and 3.9% respectively to the variance in 1 min

post-test HRR. The remaining 69.10% of the variance in 1 minute post-test HRR could not be explained by variables that were considered in this study.

**TABLE 7:** Results of the forward stepwise multiple regression analysis between the Yo-Yo IR1 aerobic fitness related variables and the 1 minute post-Yo-Yo IR1 HRR measurements (%)

Yo-Yo IR1 aerobic fitness related variables	<i>F</i> -value	Multiple <i>R</i>	<i>R</i> -square	<i>R</i> -square change	<i>p</i> -value
Yo-Yo IR1 $\dot{V}O_{2\max}$ ( $\text{ml}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$ )	4.189	0.399	0.159	0.159	0.052
RCP-HR (bpm)	3.144	0.519	0.269	0.109	0.090
RCP- $\dot{V}O_{2\max}$ (% of $\dot{V}O_{2\max}$ )	1.150	0.555	0.309	0.039	0.296

\*Significant at  $p < 0.05$ ; *R* = coefficient of multiple correlation; *R-square* = coefficient of multiple correlation squared; RCP- HR (bpm) = heart rate in beats per minute at respiratory compensation point; Yo-Yo IR1  $\dot{V}O_{2\max}$  ( $\text{ml}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$ ) = maximal oxygen uptake in milliliters per minute per kilogram body mass obtained during Yo-Yo intermittent recovery test; RCP-  $\dot{V}O_{2\max}$  (% of  $\dot{V}O_{2\max}$ ) = oxygen uptake as percentage of maximal oxygen uptake at respiratory compensation point.

Table 8 contains the results of the forward stepwise multiple regression analysis between the Yo-Yo IR1 aerobic fitness related variables and the 3-minute post-Yo-Yo IR1 HRR measurements.

**TABLE 8.** Results of the forward stepwise multiple regression analysis between the Yo-Yo IR1 aerobic fitness related variables and the 3-minute post-Yo-Yo IR1 HRR measurements (%)

Yo-Yo IR1 aerobic fitness related variables	<i>F</i> - value	Multiple <i>R</i>	<i>R</i> -square	<i>R</i> -square change	<i>p</i> -value
Final Yo-Yo IR1 level	4.374	0.407	0.165	0.165	0.048*
RCP- $\dot{V}O_{2\max}$ (% of $\dot{V}O_{2\max}$ )	1.160	0.457	0.209	0.043	0.293
RCP- $\dot{V}_E$ ( $\text{L}\cdot\text{min}^{-1}$ )	1.190	0.504	0.254	0.044	0.288

\* Significant at  $p < 0.05$ ; *R* = coefficient of multiple correlation; *R-square* = coefficient of multiple correlation squared; Final Yo-Yo IR1 level = final Yo-Yo intermittent recovery test level obtained; RCP-  $\dot{V}O_{2\max}$  (% of  $\dot{V}O_{2\max}$ ) = oxygen uptake as percentage of maximal oxygen uptake at respiratory compensation point; RCP-  $\dot{V}_E$  ( $\text{L}\cdot\text{min}^{-1}$ ) = ventilatory equivalent in liters per minute at respiratory compensation point; RCP- HR (bpm) = heart rate in beats per minute at respiratory compensation point.

The tabulated results show that final Yo-Yo IR1 level was the only Yo-Yo IR1 aerobic fitness related variable that was identified as a significant predictor of 3-minute post-Yo-Yo IR1 HRR with a contribution of 16.5% to the variance in the dependent variable. RCP-  $\dot{V}O_{2\max}$  (% of

$\dot{V}O_{2\max}$ ) and RCP- $\dot{V}E$  ( $L \cdot \min^{-1}$ ) were identified as non-significant predictors of 3-minute post-Yo-Yo IR1 HRR with a separate contribution of 4.3% and 4.4%, respectively to the prediction of 3-minute post-Yo-Yo IR1 HRR. The overall stepwise regression analysis correlation coefficient ( $R^2 = 0.254$ ) indicates that the above-mentioned variables were responsible for 25.4% of the variance in 3-minute post-Yo-Yo IR1 HRR. This would mean that variables other than the variables in this study contributed 74.60% to the variance in 3-minute post-Yo-Yo IR1 HRR results.

## DISCUSSION

Despite the potential of HRV and HRR to act as indicators of team sport participants' fitness levels, studies that have investigated these aspects in team sport participants are scarce and contradictory. In view of this, the purpose of this study was to determine the relationships between HRV and HRR as well as the fitness levels of a cohort of university-level rugby players. The study results firstly showed that non-significant correlations were found for the relationship between baseline HRV and the Yo-Yo IR1 aerobic fitness related variables. Secondly, a significant negative correlation was observed between pre-Yo-Yo IR1 HRV and RCP-HR (bpm) ( $r = -0.468$ ,  $p < 0.05$ ), whereas a significant positive correlation existed between pre-Yo-Yo IR1 HRV and RCP- $\dot{V}O_{2\max}$  (% of  $\dot{V}O_{2\max}$ ) ( $r = 0.476$ ,  $p < 0.05$ ). These correlations suggest that higher HRV values corresponded to lower HR as well as higher  $\dot{V}O_2$  values at the RCP. Players with higher pre-Yo-Yo IR1 HRV values would therefore display lower RCP-HR (bpm) and higher RCP- $\dot{V}O_{2\max}$  (% of  $\dot{V}O_{2\max}$ ) values. A lower HR and a higher  $\dot{V}O_2$  value at the RCP are according to researchers an indication of a more efficient cardiovascular system, higher aerobic endurance and better sub-maximal endurance performance (1,11,22,23). It is therefore clear that the players in this study who displayed higher aerobic endurance values were also the players who obtained the highest pre-Yo-Yo IR1 HRV values. Pre-Yo-Yo IR1 HRV values could therefore be regarded as significant predictors of the rugby players' fitness (aerobic endurance) levels.

However, further analysis showed that only a small amount of the variance in the RCP related variables (21.90% and 22.66%, respectively) could be explained or be predicted by making use of HRV. A measure of HRV (the high frequency power component ( $ms^2$ ) associated with total parasympathetic activity) accounted for 27% of the variance in an 8 week  $\dot{V}O_{2\text{peak}}$  training

response ( $r = 0.46$ ,  $p = 0.003$ ) among normal healthy sedentary subjects in a study by Hautala et al. (24). A recent study by Vesterinen et al. (46) reported that 56% of the variance in the training response due to endurance training could be explained by making use of nocturnal HRV measures among recreational endurance runners. Both of these studies stated that inter-individual variation to training response and each individual's unique autonomic and cardiac responses during exercise could be the reason for the rather low variance that could be accounted for by using HRV. These last-mentioned reasons may also possibly explain the small amount of variance in the RCP related variables that could be predicted by making use of HRV in the present study.

The forward multiple regression analysis revealed that only VT1-HR (bpm) contributed significantly ( $p \leq 0.05$ ) to post-Yo-Yo IR1 HRV, with 39.8% of the variance in HRV results that could be explained by this aerobic fitness related variable. The other two variables (RCP-HR (bpm) and RCP- $\dot{V}_E$  ( $L \cdot \text{min}^{-1}$ )) were identified as non-significant predictors of post-test HRV and collectively contributed 8.6% to the variance in post-Yo-Yo IR1 HRV. Thus the subjects with the highest HR at VT1 also exhibited the highest post-Yo-Yo IR1 HRV. In this regard researchers found that endurance trained athletes have lower heart rates as well as increased parasympathetic activity and decreased sympathetic activity at sub-maximal work rates (11). Makivic et al. (37) further showed that the post-exercise HRV is an indication of the body's response to exercise and is associated with athletic fitness. Proof for these last-mentioned findings was also provided by Hautala et al. (25) who used HRV recovery (nuHF – normalized high frequency power ( $\text{ms}^2$ ) which provides an indication of the total parasympathetic modulation in the body) to assess changes in cardiac autonomic regulation after prolonged maximal exercise in cross country skiers. They found that nuHF decreased below baseline values in the first 24 hours after competition participation and then stabilized to baseline values 48 hours after competition participation. The time of nuHF recovery inversely correlated with the  $\dot{V}O_{2\text{max}}$  of the competitors ( $r = -0.712$ ,  $p < 0.016$ ) and also significantly correlated with recovery time of R-R interval variability ( $r = 0.90$ ,  $p < 0.001$ ) (25). They therefore concluded that HRV recovery time (as measured by nuHF) following vigorous exercise, is an indication of subjects' cardiorespiratory fitness due to the fact that subjects with better developed cardiorespiratory fitness are able to quicker reactivate the parasympathetic nervous system which facilitates faster recovery. Support for this statement was also provided by Borresen and Lambert (5) and Buchheit et al. (8) who contended that the parasympathetic nervous system reactivates directly

after a bout of maximal exercise in an attempt to lower the HR and subsequently increase HRV to resting levels.

Lastly, the results with regard to the prediction of HRR showed that final Yo-Yo IR1 level was the only Yo-Yo IR1 aerobic related variable that served as a significant positive predictor of 3 min post-Yo-Yo IR1 HRR. Players who reached the highest final Yo-Yo IR1 level were, therefore, also the players whose maximal Yo-Yo IR1 heart rates declined the most 3 min post-exercise. It can be expected that the players who are the fittest will reach the highest final Yo-Yo IR1 level and would also be the players whose heart rates recover the fastest. As been mentioned before, research suggests that the fittest players will possess a more reactive autonomic response to exercise which will lead to a faster deactivation of sympathetic nervous activity and domination of the parasympathetic nervous system (5,25). Players who are the fittest (as indicated by the attainment of the highest final Yo-Yo IR1 level), will therefore show the highest HRR after exercise. However, only 16.5% of the variance in 3-minute post-Yo-Yo IR1 HRR could be explained by making use of final Yo-Yo IR1 level. Again, as been previously explained the unique autonomic cardiac response of each player to exercise may serve as a possible reason for the small percentage of 3-minute post-Yo-Yo IR1 HRR variance that could be explained by making use of final Yo-Yo IR1 level.

In view of the above-mentioned research findings, the hypothesis of the study which stated that significant relationships will exist between HRV and HRR as well as the fitness levels of a cohort of university-level rugby players, can be partially accepted. Although relationships were found between the two last-mentioned variables and the fitness levels of players, only a small part of the variance in fitness levels could be explained by HRV and HRR. However, despite the fact that the study results were not what the researchers expected, the findings seem to suggest that HRV and HRR may have the potential to act as affordable and easy measurement tools of team sport participants' fitness levels. The low contribution of HRV and HRR to the prediction of fitness levels may indicate that other factors that were not considered in this study may contribute more to the prediction of rugby players' fitness levels than HRV and HRR. In this regard fitness prediction factors that are not influenced by the ANS could possibly also be considered. In this regard Taipale et al. (45) for example showed that a relationship existed between increases in explosive leg power and significant improvements ( $p < 0.05$ ) in  $\dot{V}O_{2\max}$  and  $\dot{V}O_{2\max}$  velocity in endurance runners. From these results it is clear that explosive leg power may also act as a significant predictor of fitness levels. It can therefore be recommended that

further studies should focus on more elaborate testing protocols which also include the last-mentioned factors as part of their testing protocols when investigating possible fitness levels predictors.

Another factor that may also explain the lack of significance and the small contribution of HRV and HRR to the fitness levels of rugby players is the high individual variability in the different HRV and HRR related measurements. For instance: the individual values of the Pre-Yo-Yo IR1 HRV varied between 63 (minimum) and 101 (maximum) with a standard deviation of 9.70; the values of the Post-Yo-Yo IR1 HRV varied between 10 (minimum) and 70 (maximum) with a standard deviation of 14.20, whilst the values of the 3 min Post-Yo-Yo IR HRR (%) varied between 27.78 (minimum) and 43.62 (maximum) with a standard deviation of 4.62. The variability of all these values could have influenced the relationships between these values and the Yo-Yo IR1 aerobic fitness related variables negatively.

Lastly, research shows that many factors are thought to influence the HRV values of athletes. For example, dietary intake has been shown to influence the ANS activity of athletes (37). A non-significant correlation coefficient between the baseline and Pre-Yo-Yo IR1 HRV values of the rugby players in this study would seem to support this finding. Their average HRV values decreased from 88.5 to 79.0 due to the intake of food. Future studies would therefore also need to consider athletes diets when conducting HRV related research.

## **PRACTICAL APPLICATIONS**

This study was the first to have made use of this specific study procedure to evaluate the relationships between HRV, HRR and fitness levels (Yo-Yo IR1 aerobic fitness related variables) in team sport participants such as rugby players. Although still inconclusive, the significance of some of the correlation coefficient and multiple regression results would suggest that HRV and HRR have the potential to act as affordable and easy measurement tools of team sport participants' fitness levels. However, the high amount of variance in fitness related variables that could not be explained by making use of HRV and HRR, show that future studies would need to consider a wider range of measurements when investigating the value of certain variables to predict fitness levels. Despite of the challenges that are related to HRV and HRR research, practitioners in the field of sport science are already using HRV successfully to monitor recovery and determining training load (27). The emergence of The Bioforce Heart Rate Variability System has made the monitoring of HRV more accessible to the general public and although certain questions with regard to the value and applicability of HRV for use in the

sporting environment still need to be answered, the possible potential of using this measurement as a monitoring tool in athletes' conditioning programs cannot be overlooked.

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## **CHAPTER 4**

### **ARTICLE 2:**

#### **VALIDITY OF THE BIOFORCE HEART RATE VARIABILITY SYSTEM TO DETERMINE HEART RATE VARIABILITY OF A COHORT OF UNIVERSITY-LEVEL RUGBY PLAYERS**



# **The validity of the BioForce Heart Rate Variability System to determine the heart rate variability of a cohort of university-level rugby players**

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## **The validity of the BioForce Heart Rate Variability System to determine the heart rate variability in a cohort of university-level rugby players**

The purpose of this study was to determine the validity of the BioForce Heart Rate Variability System to determine the heart rate variability (HRV) of a cohort of university-level rugby players. A group of twenty u/21 university-level rugby players (M = 20.06, SD = 0.40 years) of a South African university's Rugby Institute were recruited to participate in this study. Heart rate variability (HRV) was measured simultaneously by the Actiheart monitor system as well as the BioForce Heart Rate Variability System over four time periods: during the morning in a fasting state just after players had woken up (baseline); in the morning just after the players ate breakfast (pre-anaerobic); after completion of a high-intensity anaerobic training session (post-anaerobic) and after completion of a 20 min recovery session (post-recovery). The majority of significant relationships ( $p < 0.05$ ) between the Actiheart and BioForce obtained HRV results were observed for the post-recovery period (Mean RR, SDNN, RMSSD and Peak LF power), followed by the pre-anaerobic period (Mean R-R and SDNN) and the baseline period (LF:HF ratio). No significant relationships were observed between the HRV results of the two apparatuses during the post-anaerobic period. Therefore to conclude, the study results suggest that the BioForce Heart Rate Variability System is especially valid to determine the HRV of team sport participants after recovery periods that follow intensive training sessions. However, the results cast a shadow of doubt over the accuracy of this apparatus when used directly after intensive training sessions.

Keywords: *BioForce Heart Rate Variability System; heart rate variability; rugby players*

## **Introduction**

Appreciable scientific advancements made by manufactures to incorporate the use of heart rate variability (HRV) into the sporting fraternity have been very successful in promoting the value of this physiological parameter to coaches, sport scientists and athletes (Makivic, Nikic, & Willis, 2013; Parrado, Garcia, Ramos, Cervantes, Rodas, & Capdevilla, 2010). However, the use of HRV in monitoring sports training is still rather uncommon despite technological advances in heart rate monitors. One reason for the reluctance to use HRV as a sport-training monitoring tool, is the need of coaches and athletes to measure HRV fast and effectively as well as interpret this parameter easily without having to purchase very expensive equipment. The emergence of the BioForce Heart Rate Variability System (Performance Sport Inc., Washington, USA) at the end of 2011 may have the potential to address this need. Although the manufacturers' web site claims that the HRV values obtained from this system correlated well with the values of the Omegawave Sport Technology System (Omegawave, Portland, Oregon, USA) (Jamieson, 2011), up until now no scientific evidence exists to prove the validity of this new apparatus.

The use of an ECG (Electrocardiograph) is the recognized and most accurate method to measure HRV (Lopes & White, 2006). However, the complexity and cost of high quality ECG equipment has made it difficult to assess HRV during and after on-field training sessions (Gamelin, Berthoin, & Bosquet, 2006). The development and availability of ECG-based devices such as the Actiheart heart rate monitor from Cambridge Neurotechnology (CamNtech Ltd., Cambridge, U.K.) that delivers more or less the same HRV values than a validated apparatus such as a standard ECG Holter monitor (Kristiansen et al., 2011), made HRV-monitoring during on-field training sessions more accessible and affordable for sport practitioners of non-contact sports. However, due to the fact that the Actiheart heart rate monitor is not suited for HRV analysis during contact sports, sport practitioners were compelled to investigate the use of wireless heart rate monitors in the last-mentioned sports. In this regard, a study by Gamelin et al. (2006) revealed that the Polar heart rate monitor (Polar S810) delivered HRV results that were not significantly different from the HRV results that were obtained from a validated ECG apparatus, and concluded that the Polar heart rate monitor was a valid instrument for determining the HRV of sport participants. Nunan et al. (2009) furthermore concluded that Polar heart rate monitors can be used to compare the HRV values between different subjects, irrespective of the finding that Polar heart rate monitors are not adequate to detect small and precise changes in HRV readings. However, despite the fact that Polar heart rate monitors are affordable and easily obtainable, the user must still make use of complex calculations and different software to obtain the HRV values.

The BioForce Heart Rate Variability System may provide practitioners in the field of Sport Science with an apparatus that has the ability to provide HRV results in a short space of time without making use of complex calculations and different software. According to the manufacturer the system has the ability to measure and provide the HRV values of a sport participant in 3 minutes by making use of a Polar heart rate transmitter belt. As been mentioned before, the developer' website claims that a high correlation exists between the HRV values obtained from the BioForce and the values obtained from the Omegawave Sport Technology System (Jamieson, 2011). The BioForce Heart Rate Variability System can therefore be regarded as a valid apparatus to measure HRV due to that fact that Berkoff, Cairns, Sanchez, and Moorman (2007) stated that the Omegawave device complies with all guidelines recommended by the task force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology Standards for Measurement of HRV. Furthermore, Parrado et al. (2010) observed no significant differences for the HRV derived indices between the Omegawave system and the Polar S810i except for the High Frequency Band and Acceleration Changes Index. They also reported significant Pearson correlations coefficients of above 0.96 ( $p < 0.05$ ) for the relationship between the HRV parameters of the two devices and concluded that both apparatuses were valid to detect R-R intervals.

Despite of the above-mentioned findings and the potential of the BioForce Heart Rate Variability System to serve as an affordable, time efficient and user-friendly apparatus to measure the HRV of athletes, no studies exist which have proven the validity of the last-mentioned apparatus to measure HRV. It is against this background that the aim of this study was to determine the validity of the BioForce Heart Rate Variability System to determine the HRV of a cohort of university-level rugby players. The results of this study will possibly indicate to people in the sporting fraternity if the BioForce Heart Rate Variability System is a valid and useful device to determine the HRV of team sport participants.

## **Methods**

### *Research design*

The design of the study was a cross-sectional experimental research design, with convenience sampling.

### *Subjects*

A group of twenty u/21 university-level rugby players ( $M = 20.06$ ,  $SD = 0.40$  years) of a South African university's Rugby Institute were recruited willingly to participate in this study. Only

rugby players actively involved and training as members of the Rugby Institute as well as those that were totally injury free at the time of testing were eligible to participate in the study. The competitive rugby-playing experience of these players varied between 4 and 12 years ( $M = 9.94$ ,  $SD = 2.67$  years). Regarding position, the group consisted of 11 backs (numbered nine to fifteen) and 9 forwards (numbered one to eight). The study design, purpose and possible risks of the study were explained to the subjects, and written informed consent was obtained from the subjects before the investigation. Subjects also completed a general information questionnaire regarding their ages, exercising habits, injury incidents, competing levels and best performances. Approval for the research was granted by the Ethics Committee of the institution where the research was conducted.

Each subject was instructed to sleep at least 8 hours during the evening and morning prior to the testing session. They also had to abstain from ingesting any drugs or participating in strenuous physical activity that may influence the physical or physiological responses of the body for at least 48 hours before the scheduled test. Subjects had to maintain the same diet during the week of testing. The subjects arrived at the testing sessions in a rested and fully hydrated state. The players were tested during the in-season phase of their periodization cycle. During the in-season phase the players participated in weight training ( $M = 1.8$ ,  $SD = 0.70$  hours per day) ( $M = 3.50$ ,  $SD = 0.90$  days per week) as well as field training sessions ( $M = 2.4$ ,  $SD = 1.20$  hours per day) ( $M = 3.9$ ,  $SD = 0.70$  days per week). During the time of testing they had already completed three months of a combined rugby conditioning program which consisted of field training sessions five times a week and gym resistance training sessions four times a week. The field training sessions were focused on rugby-specific drills, skills and activities aimed at improving the players' fitness levels. The gym resistance training sessions focused on improving players' functional muscle strength and explosive power.

### *Testing procedure*

A week before commencement of the research project the players were informed about the nature of the study, and all potential risks and benefits were explained to them. Informed consent for the investigation was also requested from the players during this session.

The research project was conducted over three consecutive days for three consecutive weeks. However, for the purpose this study only the data of week one and day one was used. During the official day of testing the players reported to the laboratory early in the morning so that baseline values could be taken. The baseline testing took place in a fasting state within ten to twenty

minutes after players had woken up in view of the fact that they had travel on their own from their places of residence to the laboratory. Each player was firstly fitted with an Actiheart monitor by placing two standard electrocardiogram (ECG) pads on the centre of the chest, horizontally across from each other by using the fourth intercostal space as a reference point. Players were also afforded the opportunity to fill in the demographic and general information questionnaire. Baseline testing also consisted of the measurement of body mass and stature as well as HRV.

Players were then allowed to eat breakfast at their own places of residence, after which they again reported to the laboratory in groups of four players each so that all the above-mentioned measurements could be repeated (pre-anaerobic period). After completion of the measurements, players were subjected to a high-intensity anaerobic training session of 15 minutes. Exactly three minutes after the anaerobic session the different measurements were again repeated (post-anaerobic period). This was followed by completion of a 20 min recovery session. Three minutes after completion of the recovery session each of the above-mentioned measurements were repeated once again (post-recovery period).

#### *Anthropometric measurements*

The anthropometric components were determined in accordance with the protocols of The International Society for the Advancement of Kinanthropometry (ISAK) (Stewart, Marfell-Jones, Olds, & De Ridder, 2011). The body mass was recorded to the nearest 0.1 kg, using a calibrated BFW 300 Platform scale (Adam equipment Co. Ltd, U.K.) and the body stature to the nearest 0.1 cm using a Harpenden portable stadiometer (Hotlain Ltd, U.K.). These measurements were taken to describe the specific cohort of rugby players with regard to their anthropometric characteristics.

#### *Heart rate variability*

During each testing period, HRV was measured with the BioForce Heart Rate Variability System (Performance Sport Inc., Washington, USA) using a Fix Polar Heart Rate Transmitter Belt as well as a wireless receiver and software that was downloaded on an iPad. Each player was requested to lie still on his back for a period of more or less 3 minutes so that the HRV could be determined. The BioForce HRV value as well as the exact time of day at which the BioForce HRV value was taken, were both noted. The BioForce Heart Rate Variability System displays a HRV value which can be categorised as follows: 0-60 = low HRV; 60-70 = fair HRV, 70-80 = moderate HRV, 80-90 = high HRV and >90 = very high HRV (Jamieson, 2012).

The Actiheart (CamNtech Ltd., Cambridge, U.K.) was also used to measure HRV due to the fact that Kristiansen et al. (2011) showed that the Actiheart HRV-derived values compared well with the HRV values that were derived from a validated apparatus (standard ECG Holter monitor). The Actiheart was worn on the chest (in accordance with the manufacturer's instructions) during the whole testing period. The Actiheart was set to measure the R to R intervals every 30 seconds for the whole testing period.

The Kubios HRV software (Version 2.1, Biosignal Analysis and Medical Imaging Group at the Department of Applied Physics, University of Kuopio, Kuopio, Finland) was used for final HRV analyses from the series of R to R intervals (variation of beat to beat) obtained from the Actiheart devices. This software has become popular and has been used in several studies that employed HRV analysis software (Nakamura et al., 2009; Perandini et al., 2009).

For validation purposes the following HRV indices were chosen out of the possible list of indices due to the fact that previous researchers approved these measurements for HRV analysis (Tarvainen & Niskanen, 2012; Task Force, 1996):

Time domain related HRV indices consisting of:

- The standard deviation of R-R intervals in milliseconds (SDNN);
- The square root of the mean squared differences between successive R-R intervals in milliseconds (RMSSD) and
- The mean of R-R intervals in milliseconds (Mean R-R).

Frequency domain related HRV indices consisting of:

- The peak low band frequencies in hertz (Peak LF power);
- The peak high band frequencies in hertz (Peak HF power) and
- The ratio between low frequency and high frequency band powers (LF:HF ratio).

Furthermore, the selected HRV indices allow researchers to assess both (the sympathetic and parasympathetic) branches of the autonomic nervous system (ANS) and are therefore fit to serve the purpose of this study.

### *Statistical analysis*

The Statistical Consultation Services of the institution where the research was conducted determined the statistical methods and procedures for the analyses of the research data. The

Statistical Data Processing package (StatSoft, 2013) was used to process the data. Firstly, the descriptive statistics (averages and standard deviations) of each of the testing variables were calculated. Secondly, Spearman's Correlation Coefficients between the baseline, pre-anaerobic, post-anaerobic and post-recovery BioForce Heart Rate Variability System and Actiheart HRV related values were determined. The level of significance was set at  $p \leq 0.05$ .

## **Results**

### *Descriptive statistics of HRV related variables*

Firstly, the descriptive statistics (averages and standard deviations values) of each of the testing variables were calculated. The descriptive statistics of the players' anthropometric measurements were as follow: length M = 181.8, SD = 5.5 centimetres; weight M = 91.1, SD = 10.7 kilograms. The HRV related variables are presented in Table 1.

Table I. Descriptive statistics for the HRV testing variables of the players ( $n = 20$ )\*

HRV variables		Baseline	Pre-Anaerobic	Post-Anaerobic	Post-recovery
BioForce HRV score		87.85 ± 8.14	82.05 ± 10.85	29.3 ± 10.98	73.75 ± 15.03
Actiheart time domain related variables	Mean R-R (ms)	942.11 ± 98.70	845.65 ± 110.37	578.63 ± 80.92	773.03 ± 115.94
	SDNN (ms)	149.57 ± 45.91	117.24 ± 49.21	57.05 ± 11.82	91.27 ± 49.17
	RMSSD (ms)	119.47 ± 37.14	101.41 ± 46.10	40.92 ± 20.16	73.92 ± 44.78
Actiheart frequency domain related variables	Peak LF power (Hz)	0.13 ± 0.11	0.14 ± 0.13	0.14 ± 0.02	0.11 ± 0.04
	Peak HF power (Hz)	0.16 ± 0.03	0.19 ± 0.08	0.17 ± 0.02	0.19 ± 0.07
	LF:HF ratio	1.99 ± 1.62	1.48 ± 1.30	0.70 ± 0.36	1.52 ± 1.44

\*Values are mean ± SD; Mean RR (ms) = Mean of R-R intervals in milliseconds; SDNN (ms) = Standard deviation of R-R intervals in milliseconds; RMSSD (ms) = Square root of the mean squared differences between successive R-R intervals in milliseconds; Peak LF power (Hz) = Peak low band frequencies in hertz; Peak HF power (Hz) = Peak high band frequencies in hertz; LF:HF ratio = Ratio between low frequency and high frequency band powers.

From the results in Table 1 it is clear that almost all of the HRV related variables showed a decrease from the baseline to the pre-anaerobic and again from the pre-anaerobic to the post-anaerobic periods. Furthermore, almost all of the HRV related variables increased from the post-anaerobic to the post-recovery period. The only HRV related variables that showed a different trend than the rest, are Peak LF (Hz) and HF Power (HZ). Peak LF Power (HZ) increased somewhat from the baseline to the pre-anaerobic period after which the value stayed constant from the pre-anaerobic to the post-anaerobic periods. The last-mentioned variable did however decrease from the post-anaerobic to the post-recovery period. Dissimilarly, HF power (Hz) showed an increase from the baseline to the pre-anaerobic periods, where after it decreased again from the pre-anaerobic to the post-anaerobic periods. An increase was however observed from the post-anaerobic to the post-recovery period.

The Spearman's Correlation Coefficient values of the relationships between the Actiheart and the BioForce HRV results are presented in Table 2.

*Results of the correlation analysis between the Actiheart and BioForce baseline HRV results*

Table 2 shows that LF:HF ratio is the only variable that correlated significantly ( $r_s = 0.46$ ,  $p < 0.05$ ) between the Actiheart and BioForce obtained HRV results. No other significant correlations were found for the relationships between the different HRV results.

*Results of the correlation analysis between the Actiheart and BioForce pre-anaerobic HRV results*

According to the results in Table 2, Mean R-R (ms) and the SDNN (ms) are the only variables that correlated significantly ( $r_s = 0.50$ , and  $r_s = 0.51$  respectively,  $p < 0.05$ ) between the Actiheart and BioForce obtained pre-anaerobic HRV results.

*Results of correlation analysis between the Actiheart and BioForce post-anaerobic HRV results*

No significant correlations were found between the Actiheart and BioForce HRV results of the post-anaerobic period.

Table II. Results of the Spearman’s Correlation Coefficient of the relationships between the Actiheart and the BioForce HRV results

		HRV variables	Baseline	Pre-Anaerobic	Post-Anaerobic	Post-recovery
Actiheart time domain related variables		Mean R-R (ms)	0.344	0.502*	-0.093	0.556*
		SDNN (ms)	0.298	0.513*	-0.043	0.683*
		RMSSD (ms)	0.263	0.395	0.309	0.609*
Actiheart frequency domain related variables		Peak LF power (Hz)	-0.249	-0.067	-0.115	-0.644*
		Peak HF power (Hz)	-0.218	0.107	-0.105	0.147
		LF:HF ratio	0.459*	0.214	0.109	0.428

\*Significant at  $p < 0.05$ ; Mean RR (ms) = Mean of R-R intervals in milliseconds; SDNN (ms) = Standard deviation of R-R intervals in milliseconds; RMSSD (ms) = Square root of the mean squared differences between successive R-R intervals in milliseconds; Peak LF power (Hz) = Peak low band frequencies in hertz; Peak HF power (Hz) = Peak high band frequencies in hertz; LF:HF ratio = Ratio between low frequency and high frequency band powers.

### *Results of correlation analysis between the Actiheart and BioForce post-recovery HRV results*

The results in Table 2 show that the majority of results correlated significantly between the Actiheart and BioForce obtained post-recovery HRV values. Mean R-R (ms) ( $r_s = 0.56, p < 0.05$ ), SDNN (ms) ( $r_s = 0.68, p < 0.05$ ), RMSSD (ms) ( $r_s = 0.61, p < 0.05$ ) and Peak LF power (Hz) ( $r_s = -0.64, p < 0.05$ ) all obtained significant correlations when the HRV results between the two last-mentioned apparatuses were analysed. Peak HF power (Hz) and LF:HF ratio were the only variables which did not reveal significant correlations for the relationship between the Actiheart and BioForce post-recovery HRV results.

### **Discussion**

Despite the potential of the BioForce Heart Rate Variability System to serve as an affordable, time efficient and user-friendly apparatus to measure the HRV of athletes and the manufacturer's claim that the HRV values obtained from this system correlated well with the Omegawave Sport Technology System, the results of this study suggest that the validity of the BioForce Heart Rate Variability System depended on the period during which subjects' HRV was determined. This finding is based on the fact that the Spearman's Correlation Coefficient analyses revealed significant relationships for the majority of HRV results (4 out of a possible 6) between the Actiheart and BioForce apparatuses for only the post-recovery period. For the pre-anaerobic period only two variables delivered significant results whereas the baseline period only delivered one significant result. No significant relationships were observed between the HRV results of the two apparatuses during the post-anaerobic period.

It is difficult to explain why the relationships between the different apparatuses' HRV related values revealed such a small number of significant results. A pivotal point in the investigation of HRV data is the manner in which the raw R-R data set is inspected and prepared by removing artifacts before further analysis (Kaufmann, Sutterlin, Schulz, & Vogele, 2011). In this regard automatic filter programs (computer based software which automatically inspects data) and manual methods (visual inspection of data by researchers) are commonly used to remove artifacts from the raw R-R data (Tarvainen & Niskanen, 2012). The researchers of this study made use of a manual method to remove artifacts from the Actiheart obtained raw R-R data compared to the BioForce Heart Rate Variability System that uses an algorithm to remove artifacts from the raw R-R data (J. Jamieson (personal communication), November 21, 2013). It is therefore possible that the named differences

in HRV data preparation may possibly serve as a reason for the small number of significant correlations between the HRV results of the Actiheart and BioForce. According to Kaufmann et al. (2011) these differences in methods that are used to process the HRV data can significantly influence the final HRV results.

As been mentioned before, the manufacturers of the BioForce Heart Rate Variability System state that the HRV results of the BioForce correlate very highly to that of the Omegawave Sport Technology System (Jamieson, 2012). They also claim that the BioForce was specifically modelled after the Omegawave (Jamieson, 2012). The results in this study, however, show that the Actiheart HRV data do not correlate very highly with the BioForce HRV data. Although more recent studies have used the Omegawave to successfully detect R-R intervals (Sanchez et al., 2011; Parrado et al., 2010; Berkoff et al., 2007), an older literature review by the Evidence-Based Practice Group (2005) under the guidance of Dr. Craig Martin concluded that there was no evidence up to 2005 that the Omegawave Sport Technology System was effective or efficient to be used as a diagnostic tool. Also, compared to other R-R detection devices (Polar, Actiheart and ECG) the Omegawave is employed considerably less in research to determine HRV indices of subjects (Parrado et al., 2010).

A further analysis of the data also revealed that especially the Actiheart obtained time domain HRV results showed significant relationships with the BioForce obtained results (five cases) whereas the Actiheart obtained frequency domain HRV results only displayed significant results in two cases. The proposed rationale for this research finding is that the BioForce Heart Rate Variability System primarily uses Ln-RMSSD (a natural logarithm applied for RMSSD) to generate the HRV results (J. Jamieson (personal communication), March 15, 2012). In view of the fact that Ln-RMSSD is a time domain related HRV index it can be expected that more significant correlations will be obtained for the relationships between the BioForce HRV and the Actiheart time domain obtained HRV results. However, research suggests that a strong relationship exists between time and frequency domain HRV indices (Task Force, 1996). In order to test this hypothesis the Spearman's Correlation Coefficients of the relationships between the time (Mean R-R, SDNN and RMSSD) and frequency domain HRV indices (Peak LF power, Peak HF power and LF:HF ratio) for the different time periods in this study, were determined. Interestingly, the correlation coefficients results revealed that SDNN correlated significantly with LF:HF ratio for the baseline ( $r_s = 0.62$ ,  $p < 0.05$ ),

pre-anaerobic ( $r_s = 0.63, p < 0.05$ ) and post-recovery periods ( $r_s = 0.61, p < 0.05$ ) as well as with Peak LF power for the baseline period ( $r_s = -0.46, p < 0.05$ ) and post-recovery period ( $r_s = -0.70, p < 0.05$ ). Another time domain HRV indice, namely Mean R-R showed significant correlations with Peak LF power ( $r_s = -0.52, p < 0.05$ ) and LF:HF ratio ( $r_s = 0.51, p < 0.05$ ) for the baseline period; with Peak HF power ( $r_s = -0.47, p < 0.05$ ) for the post-anaerobic period and with Peak LF power ( $r_s = -0.51, p < 0.05$ ) and LF:HF ratio ( $r_s = 0.47, p < 0.05$ ) for the post-recovery period.

Therefore, in contrast to what other researchers found with regard to the relationships between time and frequency domain HRV indices, the findings in this study showed that the significance of relationships between the time and frequency domain HRV indices differed according to the time periods over which the testing took place. Mean R-R and SDNN were the only time domain HRV indices that showed significant relationships with frequency domain HRV indices (especially Peak LF power and LF:HF ratio) for the majority of time periods. However, only one significant relationship was observed between the last-mentioned variables (SDNN and LF:HF ratio) for the pre-anaerobic period. The LF:HF ratio gives a indication of a fractional distribution of the spectral power and represents the sympatho-vagal interaction within the ANS (Aubert, Seps & Beckers, 2003; Perini & Veicsteinas, 2003). LF:HF ratio is therefore considered to be an index of overall ANS activity (Makivic et al., 2013). SDNN and Mean R-R (time domain HRV indices) are also regarded by researchers to be indicators of overall R-R interval variability (Pinna et al., 2007; Task Force, 1996). Therefore, in view that both sets of time and frequency domain HRV indices (SDNN and Mean R-R as well as LF:HF ratio) are indicators of overall cardiac autonomic activity (Makivic et al., 2013; Pinna et al., 2007) it is not surprising that these HRV indices are related to each other.

The finding that the validity of the BioForce Heart Rate Variability System depends on the period during which subjects' HRV was determined, is the most surprising finding of this study. No significant relationships were found between the BioForce and Actiheart for the post-anaerobic period. Furthermore, only one significant relationship was observed between the HRV results of the two apparatuses during the baseline period. The post-anaerobic HRV measurements were obtained approximately 3 minutes after a high intensity anaerobic session during which players' breathing patterns would probably be more erratic and irregular compared to the normal breathing pattern. Although the players were instructed to breathe normally during all measurements, it would have been difficult for them to control their breathing directly after a rigorous exercise session. Irregular

breathing patterns could have had an influence on the Actiheart results (Kristiansen et al., 2011). With regard to the baseline period, the players' HRV were measured during a fasting state just after they woke up in the morning. Players' breathing patterns would probably be slower and deeper during this period compared to other time periods. In this regard, Penttila et al. (2001) investigated the effects of breathing frequency on HRV indices during short-term HRV analysis. Their results showed that switching from controlled to spontaneous breathing led to a significant decrease ( $p < 0.05$ ) in the HF component (frequency domain related variable), while the RMSSD was not significantly affected ( $p < 0.05$ ). In addition, research by Plews, Laursen, Stanley, Kilding, and Buchheit (2013) showed that Ln-RMSSD was not influenced by breathing frequency. This study by Pinna, Maestri, La Rovere, Gobbi, and Fanfulla (2005) also found that the increase in the HF HRV component was significantly related ( $p < 0.05$ ) to the increase in the tidal volume of the subjects. In view that the BioForce Heart Rate Variability System primarily uses Ln-RMSSD to generate the HRV results, its measures would probably be less influenced by breathing frequency. Differences in the way that HRV is computed between the two apparatuses would therefore serve as a possible explanation for the non-significant relationships between the Actiheart and BioForce Heart Rate Variability System's HRV results during the baseline and post-anaerobic period, respectively.

## **Conclusion**

The aim of this study was to determine the validity of the BioForce Heart Rate Variability System to determine the HRV of a cohort of university-level rugby players. Overall, the results of the study showed that the validity of the BioForce Heart Rate Variability System depended on the period during which subjects' HRV was determined. The majority of significant relationships between the Actiheart and Bioforce obtained HRV results (4 out of 6 variables) were observed for the post-recovery period, followed by the pre-anaerobic period (2 out of 6 variables) and the baseline period (1 out of 6 variables). No significant relationships were observed between the HRV results of the two apparatuses during the post-anaerobic period. Differences in the methods that are used to prepare the HRV data between the two apparatuses; the use of Ln-RMSSD by the BioForce Heart Rate Variability System compared to the use of Mean R-R, SDNN, RMSSD, Peak LF power, Peak HF power and LF:HF ratio by the Actiheart apparatus to deliver the HRV values and the greater possible influence of breathing patterns on especially the HRV results of the Actiheart compared to the BioForce apparatus may all serve as possible reasons for the non-significant relationships.

Furthermore, despite the manufacturer's claim that the HRV values obtained from the BioForce Heart Rate Variability System correlated well with the values of the Omegawave Sport Technology System, the study results show that only seven out of a possible twenty-four correlation coefficients revealed significance when the relationships between the HRV indices of the BioForce Heart Rate Variability System and the Actiheart were determined. However, some researchers claim that evidence for the effectiveness or efficiency of the OmegaWave Sport Technology System as a diagnostic tool, is scarce. Also, compared to other R-R detection devices the Omegawave is employed considerably less in research to determine HRV indices of subjects.

Therefore to conclude, the study results suggest that the BioForce Heart Rate Variability System is especially valid to determine the HRV of team sport participants after recovery periods that follow hard training sessions. However, the results cast a shadow of doubt over the accuracy of this apparatus when used directly after hard training sessions. Furthermore, the fact that only six out of a possible twenty-four correlation coefficients revealed significance when the relationships between the HRV indices of the BioForce Heart Rate Variability System and the Actiheart were determined, make it difficult to verify the validity of the BioForce to determine the HRV of team sport participants. Although the results in this study would indicate that the BioForce is not a valid system for the detection of HRV in athletes, several shortcomings should be considered when interpreting the results together with recommendations for future researchers who focus on this field of study:

- A cross-sectional experimental research design with convenience sampling was used in this study. However, to test the validity of the BioForce Heart Rate Variability System, it would be advisable to make use of a randomly chosen subject group and rather use a longitudinal research design by which the validity of the last-mentioned apparatus can be tested over time. It would therefore be better to test athletes daily over a period of time in order to establish each individual's baseline HRV score and to evaluate these measures by considering the training demands of each time period.
- In this study six Actiheart obtained HRV indices were selected to serve as variables against which the BioForce Heart Rate Variability System derived HRV scores could be validated. However, future studies may also include a wider range of frequency domain, time domain and non-linear HRV indices to test the validity of the BioForce Heart Rate Variability System.
- Finally, it can also be recommended that future studies should rather make use of more than one validated apparatus when validating the BioForce Heart Rate Variability System.

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## CHAPTER 5

### SUMMARY, CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS



## 5.1 SUMMARY

The purposes of this study were firstly, to determine the relationships between heart rate variability (HRV) and recovery (HRR) as well as the fitness levels of a cohort of university-level rugby players and secondly, to verify the validity of the BioForce Heart Rate Variability System to determine the HRV in a cohort of university-level rugby players.

Chapter 1 provided a brief problem statement that culminated into research questions, objectives and the hypotheses of this study as well as the structure of the dissertation.

Chapter 2 consisted of a literature review titled: “The influence of exercise and fitness levels on heart rate variability and recovery”. The primary purpose of this chapter was to provide a review of HRV and HRR as indices to monitor ANS function in exercise and sport settings. In order to fulfill the above purpose, the following steps were followed in compiling the review: Firstly, the physiology of the ANS was explained in order to provide the reader with a better understanding of the use of HRV and HRR as tools to examine autonomic fluctuations under different physiological conditions. Secondly, methodological aspects of HRV and HRR measurements were discussed and explained. Thirdly, the value of using HRV and HRR in sport and exercise settings was discussed. Finally, limitations of using these parameters in sport and exercise were explained by making use of the available literature.

The review therefore started by showing that the ANS entirely or partially control arterial pressure, sweating, body temperature, gastrointestinal motility, gastrointestinal secretion, bladder emptying and many other physiological functions. Literature also indicated that the ANS is divided into the SNS and the PNS which have antagonistic characteristics but function synergistically. The functions of these branches of the ANS differ with the SNS that prepares and sustains the body to face a crisis, danger or stress whereas the PNS is more active when a person is calm and relaxed and little physical demand is put on the body. The end result of the relationship between the SNS and PNS is a very effective and responsive regulation of the cardiovascular system. In this regard both HRV and HRR are regarded to be established measures of cardiac ANS function and are used in sport and exercise settings. HRV is defined as a measure of the beat-to-beat variation and the time duration

between each completed cardiac cycle and HRR as the rate at which heart rate decreases (or time taken for heart rate to recover) after moderate to heavy exercise.

The review of literature showed that most researchers agree that HRV can be used as a valid physiological parameter of athletes' fitness and performance levels in view of its significant relationship ( $p < 0.05$ ) with psychophysiological status, overreaching status, overtraining, training load, body fat percentage, aerobic performances, anaerobic thresholds, Yo-Yo IR1 performance, maximal aerobic speed and recovery time after exercise in both team and individual sport participants of different participant levels. However, factors such as the pre-competition dietary preferences, hydration status, respiratory status, mood state and posture of subjects before and during measurement of HRV may significantly influence ( $p < 0.05$ ) the HRV values and lead to measurement errors.

According to research, HRV is usually measured by determining the time that elapses between two R-R cycles and then quantifying these values by analysing it through HRV analysis software in order to obtain HRV parameters for interpretation. Validated and accurate devices that are the most frequently employed for HRV analysis were found to be an electrocardiograph (ECG) as well as the Polar heart rate monitors. Another less well known device such as the Actiheart was also found to be a valid and accurate measure of HRV. Devices used by the sporting fraternity such as the BioForce and Iathlete heart rate variability systems should be validated by scientific studies to ensure their accurateness.

Although research on the use of HRR as a measure of cardiac ANS function is not as common as HRV related research, findings showed that HRR can be used as a significant indicator ( $p < 0.05$ ) of training program adaptations and effectiveness, overtraining, aerobic performance, physical fitness and recovery for a wide range of individual and team sport participants. HRR can however also be significantly influenced ( $p < 0.05$ ) by ingesting energy drinks and alcohol.

Absolute or relative HRR values are usually obtained by measuring heart rate with a heart rate monitor at the cessation of a maximal or sub-maximal exercise and then again post-exercise at a certain time point. The percentage decrease for exercise heart rate to post-exercise heart rate is then calculated.

Chapter 3 consisted of the first article which was compiled in accordance with the guidelines of the *Journal of Strength and Conditioning Research* and entitled: “The use of heart rate variability and recovery to determine the fitness levels of a cohort of university-level rugby players”. The purpose of this study was to determine the relationships between HRV and HRR as well as the fitness levels of a cohort of university-level rugby players. The study results firstly showed that non-significant correlations were found for the relationship between baseline HRV and the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1) aerobic fitness related variables. Secondly, a significant negative correlation was observed between pre-Yo-Yo IR1 HRV values and heart rate at the respiratory compensation point (RCP) ( $r = -0.468$ ,  $p < 0.05$ ), whereas a significant positive correlation existed between pre-Yo-Yo IR1 HRV values and oxygen uptake at the RCP ( $\% \text{ of } \dot{V}O_{2\max}$ ) ( $r = 0.476$ ,  $p < 0.05$ ). Further analysis showed that only a small amount of the variance in the RCP related variables could be explained or predicted by making use of HRV (21.90% and 22.66%, respectively). The forward multiple regression analysis revealed that only the heart rate at ventilatory threshold one (VT1) contributed significantly to post-Yo-Yo IR1 HRV values. The other two variables (heart rate at the RCP and minute ventilation at the RCP) were identified as non-significant predictors of post-test HRV. Lastly, the results with regard to the prediction of HRR showed that final Yo-Yo IR1 level was the only Yo-Yo IR1 aerobic related variable that served as a significant positive predictor of 3 minute post-Yo-Yo IR1 HRR. However, only 16.5% of the variance in 3 minute post-Yo-Yo IR1 HRR could be explained by making use of final Yo-Yo IR1 level.

Chapter 4 consisted of the second article titled: “The validity of the BioForce Heart Rate Variability System to determine the heart rate variability of a cohort of university-level rugby players”. This article was compiled according to guidelines of the *European Journal of Sport Science*. The purpose of this study was to verify the validity of the BioForce Heart Rate Variability System to determine the HRV of a cohort of university-level rugby players. The results of this study suggested that the validity of the BioForce Heart Rate Variability System depended on the period during which subjects’ HRV was determined. This finding is based on the fact that the Spearman’s Correlation Coefficient analyses revealed significant relationships ( $p < 0.05$ ) for the majority of HRV results (4 out of a possible 6) between the Actiheart and Bioforce apparatuses for only the post-recovery period. For the pre-anaerobic period only two variables delivered significant results ( $p < 0.05$ )

whereas the baseline period only delivered one significant result. No significant relationships were observed between the HRV results of the two apparatuses during the post-anaerobic period.

## 5.2 CONCLUSIONS

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

**Hypothesis 1:** *Significant positive relationships will exist between HRV and HRR as well as the fitness levels of a cohort of university-level rugby players.* Hypothesis 1 is accepted, based on the fact that significant positive relationships were found between the two last-mentioned variables and the fitness levels of players. However, only a small part of the variance in fitness levels could be explained by HRV and HRR. Despite this HRV and HRR seem to possess the potential to predict the fitness levels of a cohort of university-level rugby players.

**Hypothesis 2:** *The BioForce Heart Rate Variability System is a valid system to determine the HRV in a cohort of university-level rugby players.* Hypothesis 2 is rejected, based on the fact that the study results showed that seven out of a possible twenty-four correlation coefficients revealed significance when the relationships between the HRV indices of the BioForce Heart Rate Variability System and the Actiheart were determined. However, the study results also suggested that the BioForce Heart Rate Variability System is valid to determine the HRV of team sport participants after recovery periods that follow hard training sessions.

## 5.3 LIMITATIONS AND RECOMMENDATIONS

To the researcher's knowledge this is the first study to have made use of this specific study procedure to evaluate the relationships between HRV, HRR and fitness levels (Yo-Yo IR1 aerobic fitness related variables) in team sport participants such as rugby players. Although still inconclusive, the significance of some of the correlation coefficient and multiple regression results in this study would suggest that HRV and HRR have the potential to act as affordable and easy measurement tools of team sport participants' fitness levels.

Furthermore, it is also the first study to evaluate the validity of the BioForce Heart Rate Variability System to determine the HRV of team sport participants such as rugby players. The study results did however show that the validity of the BioForce Heart Rate Variability System depends on the period during which subjects' HRV is determined.

Although many questions still remain with regard to the use of HRV and HRR as fitness level predictors among rugby players and the validity of the BioForce Heart Rate Variability System, practitioners in the field of sport science are already using HRV successfully to monitor recovery and determining training load. However, researchers who want to investigate the suitability and accuracy of HRV and HRR as well as the validity of different apparatuses that can be used to determine these variables will need to consider the following shortcomings of this study as well as recommendations for future studies:

- The inter-individual variation in HRV and HRR due to each individual's unique autonomic and cardiac responses during exercise may affect the HRV results that are found when conducting HRV related studies. Studies in which individuals are monitored over a period of time in order to find trends with regard to each individual's unique HRV training response would therefore provide more clarity concerning individual changes in HRV response over time.
- Various other factors influence the HRV and HRR values of athletes. For example, athletes' dietary intake, hydration status, mood states and recovery status are all factors that may influence autonomic nervous system activity. As such, it can be recommended that future studies should monitor each of these last-mentioned factors when evaluating athletes' HRV and HRR responses. The inclusion of these factors as possible co-variables in the statistical analyses will possibly allow researchers to determine the exact influence of each of these factors on the HRV results.
- The low contribution of HRV and HRR to the prediction of rugby players' fitness levels may indicate that other factors that were not considered in this study may contribute more to the prediction of rugby players' fitness levels than HRV and HRR. In this regard fitness prediction factors that are not influenced by the ANS could possibly also be considered. It can therefore be recommended that further studies should focus on more elaborate testing protocols which also include the last-mentioned factors as part of their testing protocols when investigating possible fitness levels predictors

- A cross-sectional experimental research design with convenience sampling was used in this study. However, to test the validity of the BioForce Heart Rate Variability System, it would be advisable to make use of a randomly chosen subject group and rather use a longitudinal research design by which the validity of the last-mentioned apparatus can be tested over time. It would therefore be better to test athletes daily over a period of time in order to establish each individual's baseline HRV score and to evaluate these measures by considering the training demands of each time period.
- In this study six Actiheart obtained HRV indices were selected to serve as variables against which the BioForce Heart Rate Variability System derived HRV scores could be validated. However, future studies may also include a wider range of frequency domain, time domain and non-linear HRV indices to test the validity of the BioForce Heart Rate Variability System.
- Finally, it can also be recommended that future studies should rather make use of more than one validated apparatus when validating the BioForce Heart Rate Variability System.



**1.5 Permanent postal address in South Africa:**


**1.6 Phone numbers:**

<u>Home:</u>	<u>Work:</u>
<u>Fax:</u>	<u>Cell:</u>
<u>E-mail:</u>	

**1.7 Ethnic group**

White	Coloured	Black	Indian
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*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
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**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
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**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
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**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
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**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
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**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
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**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
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**2.8 Do you spend any time on psychological preparation for rugby and competitions?**

Never	*Sometimes	*Often	*Always
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**\* Please specify the type of psychological preparation you do if you marked any of these three options:**

<hr/> <hr/> <hr/> <hr/> <hr/> <hr/> <hr/> <hr/> <hr/> <hr/>
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**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):**

<b>Head/Neck:</b> <hr/> <hr/> <hr/> <hr/> <hr/>
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**Shoulder/Clavicle:**

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**Arm/Elbow/Wrist/Hand:**

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**Back:**

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**Hip/Pelvis:**

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**Thigh/Knee:**

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**Lower leg/Ankle/Foot:**

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**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?**

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

Club:	Provincial:	National:	International:
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**4.3 How many matches, approximately, have you played?**

Club:	Provincial/National:
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**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 validity of the BioForce Heart Rate Variability (HRV) System and the use of heart rate variability and recovery to determine the fitness levels and recovery of a cohort of university-level rugby players.

**3. Full names, surname and qualifications of project leader:**

Ben Coetzee, B.Sc., B.Sc. (Hons), M.Sc. and PhD

**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 determine the relationships between heart rate variability and recovery as well as fitness level changes in a cohort of university-level rugby players.
- To determine the validity of the BioForce Heart Rate Variability System to determine the heart rate variability in a cohort of university-level rugby players.

To determine the effects of various recovery techniques (cold water immersion (CWI), contrast

temperature water therapy (CTWT), breathing and self-myofascial release techniques (BSRT) and passive recovery (PR)) on the lower and upper body explosive power output, forearm strength, several haematological analytes, HRV, as well as certain psychological parameters in a cohort of university-level rugby players.

- To determine if there is a statistical significant relationship between several indicators of recovery (upper body explosive power output, forearm strength, several haematological analytes, as well as certain psychological parameters) and HRV in a cohort of university-level rugby players.
- To determine the effect of dietary intake on the HRV in a cohort of university-level rugby players.
- To determine the normal dietary practices, supplement use and nutritional knowledge of a cohort of university-level rugby players.

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

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

The subjects will consist of two groups of rugby players. Twenty-four u/21 rugby players of the North-West University (Potchefstroom Campus, South Africa) will be randomly selected from the first and second u/21 rugby teams. The twenty-four players will be randomly divided into two groups of twelve players each. One group will form the experimental group and the other the control group.

### **b) *Procedures***

#### **i. Demographic and general information questionnaire:**

The players' demographic and personal information will be collected by means of a demographic and general information questionnaire. The players' ages, exercising habits, injury incidence and competing levels will also be obtained by means of the questionnaire. Anthropometric data will be collected by taking a few body measurements and the physical and motor performance data by means of a test battery. The HRV data will be collected by means of the Polar Team<sup>2</sup> Pro Electro system (Polar Electro, Kempele, Finland), the Actiheart® (CamNtech Ltd, Cambridge, UK) and the BioForce Heart Rate Variability System (8Weeks.Out). The blood samples will be analysed by a Simplified Blood Lactate Test Meter Lactate Pro LT-1710 (Arkray Factory Inc., KDK Corporation, Shinga, Japan) and the i-STAT clinical portable analyzer (Abbott Point of Care, Illinois, USA).

#### **ii. Anthropometric measurements and components:**

The body mass will be recorded to the nearest 0.1 kg, using a calibrated a portable electronic scale (Beurer Ps07 Electronic Scale, Ulm, Germany). A Harpenden portable stadiometer (Holtain Limited, Crosswell, UK.) with a perpendicular board will be used to take this measurement to the nearest 0.1 cm.

#### **iii. Physical and motor ability components:**

The players will be subjected to a test battery for the measurement of lower and upper body explosive power output (Vertical Jump Test (VJT) and Smith Machine Bench throw Test (SMBT)) as well as forearm strength (GST: Grip Strength Test).

iv. Haematological measurements:

Venous blood samples will be collected at various time intervals during the duration of data collection. The concentrations of thirteen haematological analytes will be determined by drawing capillary blood samples from the hyperaemic fingertip and collecting it into duplicate, 100µL heparinised capillary tubes (Bacto Laboratories Pty Ltd, New South Wales, Australia) after which the blood will be expelled into the sample wells of two CG4<sup>+</sup> cartridges. One cartridge at a time will then be inserted into the i-STAT clinical portable analyzer to be analyzed 120 seconds. The concentrations for the following haematological analytes will be obtained: the partial pressures of oxygen (PO<sub>2</sub>) and carbon dioxide in the blood (PCO<sub>2</sub>); oxygen saturation (SaO<sub>2</sub>), bicarbonate content (HCO<sub>3</sub><sup>-</sup>), blood pH, total CO<sub>2</sub> (TCO<sub>2</sub> = the sum of the CO<sub>2</sub> and the HCO<sub>3</sub><sup>-</sup>), base excess (the amount of strong acid that must be added to each liter of fully oxygenated blood to return the pH to 7.40 at a temperature of 37°C and a PCO<sub>2</sub> of 40mmHg); blood sodium, potassium and ionized calcium; blood glucose, hematocrit and hemoglobin. Blood from the capillary blood samples will also be used to analyse the blood lactate by means of a Simplified Blood Lactate Test Meter Lactate Pro LT-1710.

Prior to sampling, the punctured site will be cleaned with an alcohol wipe, dried and the first drop post-puncture will be excluded from the sample.

v. Urine-related measurements:

Players will also be requested to collect their urine for 24 hours in a special container during the duration of data sampling. On day one of urine collection, the players will be requested to urinate into the toilet when they get up in the morning. Afterwards all urine will be collected in a special container for the next 24 hours. On day two they will be requested to urinate into the container when they get up in the morning. Afterwards they will need to cap the container. The urine must be kept in a refrigerator during the collection period. Each container will be labeled with the player's name before urine collection. The urine nitrogen levels will then be determined from the repeated 24 hour urine collections to validate the dietary assessments that are going to take place.

vi. Dietary intake assessment:

A 7 day diet record (Rankin *et al.*, 2010) combined with urine nitrogen measures (Bingham, 2003) and an unique statistical triad model (McNaughten *et al.*, 2005) will be used to determine and validate the dietary intake of the players. An adapted questionnaire which were compiled from the validated supplement use questionnaire of Walsh *et al.* (2011) will used to obtain information with regard to the dietary and hydration practices of the rugby players before, during and after training and games was. Questions from previously published studies in which questionnaires were used to evaluate the nutritional knowledge of subjects, were also combined and inserted into the adapted questionnaire to determine the nutritional knowledge of the players (Gracey *et al.*, 1995; Nichols *et al.*, 2005; Rosenbloom *et al.*, 2002).

vii. HRV determination:

During each testing period HRV will be determined by making use of the Polar Team<sup>2</sup> Pro Electro system together with the BioForce Heart Rate Variability System. The Actiheart will also be used to measure HRV due to the fact that Kristiansen *et al.* (2011:12) showed that the Actiheart HRV derived values compared well with the HRV values that were derived from a validated apparatus. The Actiheart will be worn on the chest and consists of two electrodes connected by a short lead which simply clip onto two standard electrocardiogram (ECG) pads. The following parameters will also be obtained from the Actiheart date: resting heart rate, activity energy expenditure (AEE) and physical activity level. The Actiheart will be worn for 48 hours. However, the players will only wear the Polar Heart Rate

Transmitter belts of the Polar Team<sup>2</sup> Pro during the testing periods. The heart rate data from the Polar system will then be used by the BioForce Heart Rate Variability System to determine HRV during different testing periods.

viii. Psychological parameters:

The Stellenbosch Mood Scale (STEMS) (Terry *et al.*, 2003), which is based on the Profile of Mood States-A of Terry *et al.* (1999, 2003) will be administered several times during the course of the data sampling period to assess the mood construct of the players. Furthermore, the Recovery-Stress Questionnaire for Athletes (RESTQ-Sport) (Kellman & Kallus, 2001) will also be administered before and after each 48 hour period during data collection to ascertain the recovery-stress states of athletes. .

ix. Recovery techniques:

The players will be subjected to three different recovery techniques during the data collection period:

*CWI*: This will consist of cold water immersion in a cryotherapy bath. The experimental group will submerge themselves in the bath up to their umbilicus for a period of 20 min while standing still. The cryotherapy bath will be regulated at a temperature of  $8 \pm 1^{\circ}\text{C}$ .

*CTWT*: During this recovery technique players will be required to submerge themselves in a warm water pool, which will be regulated at a temperature of  $38 \pm 1^{\circ}\text{C}$  up to their umbilicus for a period of 3 min while standing still, followed by a quick transfer to an adjacent cryotherapy bath ( $8 \pm 1^{\circ}\text{C}$ ) where they will also submerge themselves up to their umbilicus for 1 min. This 4-minute regimen will be completed five times so that the total recovery period works out to 20 min.

*BSRT*: The players will be firstly be subjected to self-myofascial release techniques during which players will be subjected to 45 sec of foam rolling activities for each of the following body parts on the left and right side respectively: Quadriceps, Hamstrings, Gluteus group, Illiopsoas, Gastrocnemius, Tibialis Anterior, Trapezius, Lattisimus Dorsi, Pectoralis Major and lower back muscles. This will be followed by 10 min of breathing exercises which will focus on diaphragmatic breathing.

*PR*: The control group will be subjected to PR during which they will stay seated for the 20 min duration.

x. Anaerobic session:

Player will be subjected to an anaerobic training session for a period of 15 min. During this period players will perform high intensity running and shuffling movements. This will also be combined with rugby specific movements and drills.

xi. Testing procedure:

A few days before the commencement of the research project the players will be informed of the nature of the study, and all potential risks and benefits will be explained to them. Informed consent for the investigation will also be requested from the players during this session. This session will also be used to hand out the 7 day diet records and the scales that will be used to measure the portions of the different foods that are eaten during the 7 day period.

*On day one:* Players will report to the project leader at the Sport Science laboratory from 6:00-8:00 in the morning during which baseline testing will take place. Players will not be allowed to eat before they are subjected to the baseline testing. Four players at a time will be measured. Firstly each player will be fitted with the Actiheart and an electrode belt will be strapped around the chest at the lower sternum of each player. Next, the players' stature and weight will be measured after which blood samples will be obtained. This will be followed by the measurement of HRV for a period of 3-5 min. Next, the execution of the VJT, SMBT and GST will take place. Players will then fill in the RESTQ-Sport and the STEMS. Later, during the same day the procedure will be repeated after which each of the players will be subjected to the anaerobic session of 15 min. After this, the testing procedure will be repeated, followed by either the CWI or PR session, according to the allocation to either the experimental or control group. After the recovery techniques the players will again be subjected to the above-mentioned testing procedures.

*On day two:* Players will report to the project leader at the Sport Science laboratory from 6:00-8:00 in the morning during which testing will take place. Players will not be allowed to eat before they are subjected to the testing. Four players at a time will be measured. Firstly an electrode belt will be strapped around the chest at the lower sternum of each player. Next, the players' weight will be measured after which blood samples will be obtained. This will be followed by the measurement of HRV for a period of 3-5 min. Next, the execution of the VJT, SMBT and GST will take place. Players will then each receive a special container so that urine collection can take place for 24 hours. Players will then fill in the RESTQ-Sport and the STEMS. Later, during the afternoon of the same day the procedure will be repeated.

*On day three:* Players will report to the project leader at the Sport Science laboratory from 6:00-8:00 in the morning during which testing will take place. Players will not be allowed to eat before they are subjected to the testing. Four players at a time will be measured. Firstly an electrode belt will be strapped around the chest at the lower sternum of each player. Next, the players' weight will be measured after which blood samples will be obtained. This will be followed by the measurement of HRV for a period of 3-5 min. Next, the execution of the VJT, SMBT and GST will take place. Players will then fill in the RESTQ-Sport and the STEMS. Later, during the afternoon of the same day the procedure will be repeated. Players will then hand in their containers which contains the 24-hours urine collection. The Actiheart will also be removed.

The same procedures will then be repeated for two weeks after the first week of testing, with the only difference that the recovery techniques will be changed to CTWT and PR as well as BSRT and PR respectively.

**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:**

Each of the researchers will wear protective gloves and each of the fingers will be cleaned thoroughly by making use of alcohol wipes before blood sampling to prevent any infections from occurring. The fact that the capillary puncture to the fingertip is much more comfortable and

convenient for the subjects than the more invasive procedures to draw blood, led the researchers to rather make use of this technique. Only players who form part of the u/21 rugby teams of the PUK Rugby Institute and who have been participating in a structured physical conditioning program will be allowed to participate in the project. The temperature of the laboratory will be monitored and regulated to ensure that the players do not experience discomfort during the execution of the different tests.

**11. Description of the benefits which may be expected from this project:**

The results of this study will possibly provide coaches and other sport related professionals with information regarding the accurateness and usefulness of HRV and heart rate recovery as indicators of fitness level changes and recovery in a cohort of rugby players. It may also give people in the sporting fraternity an indication of the validity and usefulness of the BioForce Heart Rate Variability System to determine the heart rate variability of team sport participants. Furthermore, players will obtain information with regard to their dietary habits, sleeping patterns and haematological profile.

**12. Alternative procedures which may be beneficial to the subjects:**

*(Complete only if applicable.)*

As part of the project players will also receive a written dietary regimen which will help them to eat healthier.

**Signature:** .....

**Date:** 10/05/2012

**Project leader**

## **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 validity of the BioForce Heart Rate Variability (HRV) System and the use of heart rate variability and recovery to determine the fitness levels and recovery of a cohort of university-level rugby players.

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 .....

**APPENDIX B:**  
**DATA COLLECTION FORMS**

**RAW DATA FOR HRV – NAME OF PLAYER:** \_\_\_\_\_

<b>BASE LINE TEST (EARLY MORNING)</b>			
<b>TEST COMPONENT</b>	<b>1<sup>ST</sup> READING</b>	<b>2<sup>ND</sup> READING</b>	<b>MEAN</b>
BODY MASS (KG)			
BODY STATURE (CM)			
<b>TEST COMPONENT</b>	<b>1<sup>ST</sup> READING</b>	<b>2<sup>ND</sup> READING</b>	<b>MEAN</b>
R: BICEPS SKINFOLD (MM)			
R: TRICEPS SKINFOLD (MM)			
R: SUBSCAPULAR SKINFOLD (MM)			
R: SUPRASPINALE SKINFOLD (MM)			
ABDOMINAL SKINFOLD (MM)			
R: FRONT THIGH SKINFOLD (MM)			
R: MEDIAL CALF SKINFOLD (MM)			
<b>TEST COMPONENT</b>	<b>1<sup>ST</sup> READING</b>	<b>2<sup>ND</sup> READING</b>	<b>MEAN</b>
R: HUMERUS BREADTH (CM)			
R: WRIST BREADTH (CM)			
R: FEMUR BREADTH (CM)			
R: ANKLE BREADTH (CM)			
<b>TEST COMPONENT</b>	<b>1<sup>ST</sup> READING</b>	<b>2<sup>ND</sup> READING</b>	<b>MEAN</b>
R: RELAXED ARM GIRTH (CM)			
R: FLEXED ARM GIRTH (CM)			
<b>TEST COMPONENT</b>	<b>1<sup>ST</sup> READING</b>	<b>2<sup>ND</sup> READING</b>	<b>MEAN</b>
R: MID THIGH GIRTH (CM)			
R: MAXIMUM CALF GIRTH (CM)			
R: FOREARM GIRTH (CM)			
<b>TEST COMPONENT</b>	<b>1<sup>ST</sup> TIME</b>		
HR (BPM)			
HRV			
TIME OF HRV (H:MIN:SEC)			

<b>PRETEST</b>				
<b>TEST COMPONENT</b>		<b>1<sup>ST</sup> READING</b>	<b>2<sup>ND</sup> READING</b>	<b>MEAN</b>
BODY MASS (KG)				
<b>TEST COMPONENT</b>		<b>1<sup>ST</sup> TIME</b>		
HR (BPM)				
HRV				
TIME OF HRV (H:MIN:SEC)				
<b>YO-YO TEST</b>				
<b>LEVEL</b>	<b>HEART RATE</b>	<b>SHUTTLE NUMBER</b>		
5				
9				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
<b>TEST COMPONENT</b>		<b>1<sup>ST</sup> TIME</b>		
HRR AT 1 MIN POST YO-YO (BPM)				
HRR AT 3 MIN POST YO-YO (BPM)				
HRR AT 5 MIN POST YO-YO (BPM)				
<b>TEST COMPONENT</b>		<b>1<sup>ST</sup> TIME</b>		
HR (BPM)				
HRV				
TIME OF HRV (H:MIN:SEC)				

**RAW DATA FOR HRV – NAME OF PLAYER AND NUMBER:** \_\_\_\_\_

<b>BASE LINE TEST (TUESDAY MORNING) (15 MAY)</b>	
<b>TEST COMPONENT</b>	<b>1<sup>ST</sup> TIME</b>
BODY MASS (KG)	
BODY STATURE (CM)	
HRV	
TIME OF HRV (H:MIN:SEC)	
<b>PRE-ANAEROBIC SESSION (TUESDAY MORNING)</b>	
<b>TEST COMPONENT</b>	<b>1<sup>ST</sup> TIME</b>
HRV	
TIME OF HRV (H:MIN:SEC)	
<b>POST-ANAEROBIC SESSION (TUESDAY MORNING)</b>	
<b>TEST COMPONENT</b>	<b>1<sup>ST</sup> TIME</b>
HRV	
TIME OF HRV (H:MIN:SEC)	
<b>POST-RECOVERY SESSION 1 (TUESDAY MORNING)</b>	
<b>TEST COMPONENT</b>	<b>1<sup>ST</sup> TIME</b>
HRV	
TIME OF HRV (H:MIN:SEC)	

# **APPENDIX C:**

## **GUIDELINES FOR AUTHORS OF THE JOURNAL OF STRENGTH AND CONDITIONING RESEARCH**

### **MANUSCRIPT SUBMISSION GUIDELINES**

Manuscripts may be submitted on-line at <http://www.editorialmanager.com/JSCR> or by email following the instructions below. When submitting by email, only one copy is required of each document including a copyright form.

1. If by email, authors should submit a MicrosoftWord (.doc) file.
2. 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.
3. 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/>.
4. 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.
5. All manuscripts must be double-spaced with an additional space between paragraphs. The paper should include a minimum of 1-inch margins and page numbers in the upper right

corner next to the running head. 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/>.

6. 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.”
7. There is no word limitation but authors are instructed to be concise and accurate in their presentation and length will be evaluated by the Editor and reviewers for appropriateness.

## MANUSCRIPT PREPARATION

### 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); Wellcome 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 to send to the reviewers in our double blind process of review. Do not place identifying information in the Acknowledgement portion of the paper or anywhere else in the manuscript.

### 3. Abstract and Key Words

On a separate sheet of paper, the manuscript must have an abstract with a limit of 250 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.

### 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. 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. “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.,  $P \neq 0.05$ ). 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.
- 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 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.

## 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 45 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, [ftp://support.isiresearchsoft.com/pub/pc/styles/endnote4/J Strength Condition Res.ens](ftp://support.isiresearchsoft.com/pub/pc/styles/endnote4/J%20Strength%20Condition%20Res.ens). may be downloaded for use in the End Note application: [ftp://support.isiresearchsoft.com/pub/pc/styles/endnote4/J%20 Strength%20Condition%20Res.ens](ftp://support.isiresearchsoft.com/pub/pc/styles/endnote4/J%20Strength%20Condition%20Res.ens).

Below are several examples of references:

- **Journal Article**

Hartung, GH, Blancq, 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*. J.K. Richardson and Z.A. Iglarsh, eds. Philadelphia: Saunders, 1994. pp. 159–199.

- **Software**

Howard, A. *Moments ½software\_*. 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*. G. Tenenbaum and T. Raz-Liebermann, 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.

## 7. **Tables**

Tables must be double-spaced on separate sheets 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.

## 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 in Sport and Exercise, the JSCR Editorial Board endorses the use of the following terms and units.

The units of measurement shall be Systeme International d'Unite's (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<sub>min</sub><sup>-1</sup>kg<sup>-1</sup>.

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<sup>-1</sup> = 6.118 kg·m·min<sup>-1</sup>.

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 what use to be called IIb fibers. Smerdu, V, Karsch-Mizrachi, I, Campione, M, Leinwand, L, and 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.

**EXAMPLE OF AN ARTICLE PUBLISHED IN THE  
JOURNAL OF STRENGTH AND CONDITIONING RESEARCH**

## APPENDIX D:

# GUIDELINES FOR AUTHORS OF THE EUROPEAN JOURNAL OF SPORT SCIENCE

### Manuscript preparation

#### 1. General guidelines

- Papers are accepted only in English. British English spelling and punctuation is preferred. The authors are encouraged to have their paper checked by a native English speaker. Please use double quotation marks, except where “a quotation is ‘within’ a quotation”.
- A typical article will not exceed 4000 words not including tables/references/figure captions /endnotes. Papers that greatly exceed this will be critically reviewed with respect to length. Authors should include a word count with their manuscript. A maximum of 40 references and 4 illustrations (tables or figures) is permitted.
- Manuscripts should be compiled in the following order: title page; abstract; keywords; main text; acknowledgments; references; table(s) with caption(s) (on individual pages); figure caption(s) (as a list).
- Abstracts of approximately 250 words are required for all papers submitted.
- Each paper should have 3-6 keywords.
- Symbols, units and abbreviations in papers must confirm to the *Système International d'Unités* (SI Units). Authors are advised to consult the National Physical Laboratory publication (R.J.Bell (ed) 1993, *SI: The International System of Units*. London. HMSO). For all abbreviations other than units, write the word or words to be abbreviated in full on the first mention, followed by the abbreviation in parentheses.
- When numeric values are given, a space must appear between the number and unit, as in 95.6 W and 25.0 N (exceptions are angles in degrees, e.g. 23.5°, and percentages, e.g. 15%). Separate compound units by a raised dot (N·m) and not by a space (N m); a compound unit formed from others by division should be indicated, for example, as ml·min<sup>-1</sup> not as ml/min. Angular velocities should be expressed in rad·s<sup>-1</sup> not degrees s<sup>-1</sup> or ° s<sup>-1</sup>. Some exceptions to the use of the SI are allowed, for example for heart rate (beats·min<sup>-1</sup>) and

blood or gas pressure (mmHg). Other units and abbreviations should conform to Bell (1993) or Council of Biology Editors (1994).

- Scalar variables or constants that are represented by a single letter should appear in italics (e.g.  $v$ ,  $k$ ,  $x$ ). Where the abbreviation is of more than one letter (excluding suffices or superfixes), it should be set in Roman typeface, as should abbreviations of mathematical functions (thus  $a = dv/dt$ ). Vectors should be indicated in bold and italics (e.g.  $F$ ,  $v$ ). For further and more detailed examples, authors should consult Council of Biology Editors (1994). Equations and formulae should, wherever possible, be presented on one line.
- Statistical definitions and symbols should conform to ISO3534- 1977, summarized briefly in Council of Biology Editors (1994). Some examples should make matters clear:  $F_{2,12}$ ,  $H_0$ ,  $t$ ,  $n=10$ ,  $P < 0.05$ ,  $r = 0.71$  (or for population correlation coefficient),  $s$ , (for standard deviation of sample and population),  $s_x$  (standard error of the mean),  $\bar{x}$  (upper case for population mean). Mean values with standard deviations or standard errors of the mean should be reported as, for example: mean value 13.7,  $s = 2.5$  m, or mean 15.7,  $s_x = 3.6$  kg (no need for  $\pm$ ). In tables and lists, the following is convenient (mean $\pm$ s) or ( $\pm$ s), with the tabulated values in the form:  $13.4 \pm 7.2$ . Authors should, therefore, avoid the use of abbreviations such as S.D. and S.E.M.
- Search engine optimization (SEO) is a means of making your article more visible to anyone who might be looking for it. Please consult our guidance here.
- Section headings should be not be numbered.
- All the authors of a paper should include their full names, affiliations, postal addresses, telephone numbers and email addresses on the cover page of the manuscript. One author should be identified as the corresponding author. The affiliations of all named co-authors should be the affiliation where the research was conducted. If any of the named co-authors moves affiliation during the peer review process, the new affiliation can be given as a footnote. Please note that no changes to affiliation can be made after the article is accepted. Please note that the email address of the corresponding author will normally be displayed in the article PDF (depending on the journal style) and the online article.
- Biographical notes on contributors are not required for this journal.
- For all manuscripts non-discriminatory language is mandatory. Sexist or racist terms should not be used.
- Authors must adhere to SI units . Units are not italicised.

- When using a word which is or is asserted to be a proprietary term or trade mark, authors must use the symbol ® or TM.

## **2. Style guidelines**

- Description of the Journal's article style
- Description of the Journal's reference style
- Guide to using mathematical symbols and equations

**EXAMPLE OF AN ARTICLE PUBLISHED IN THE  
EUROPEAN JOURNAL OF SPORT SCIENCE**

**APPENDIX E:**  
**LETTER FROM LANGUAGE EDITOR**

November 30, 2013



**To whom it may concern**

**Re: Letter of confirmation of language editing**

The MSc dissertation “*The validity of the BioForce Heart Rate Variability System and the use of heart rate variability and recovery to determine the fitness levels of a cohort of university-level rugby players*” by Christo Alfonzo Bisschoff (13234358) was language, technically and typographically edited. The sources and referencing technique applied was checked to comply with the specific Harvard technique as per North-West University prescriptions. The referencing technique employed in the two articles (chapters 3 and 4) pertain to the specific journal guidelines. Final corrections as suggested remain the responsibility of the student.

**Antoinette Bisschoff**

Officially approved language editor of the NWU since 1998

Member of SA Translators Institute (no. 1001891)