

**Relationships between 24-hour diet and autonomic markers
of heart rate of badminton players**

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DECLARATION

The co-authors of the two articles, which form part of this dissertation, Prof Ben Coetzee (supervisor), Dr Christo Bisschoff (co-supervisor) and Dr Chrisna Botha-Ravyse (assistant-supervisor) hereby give permission to the candidate, Mr Pierre Bonthuys to include two articles as part of the MHsc dissertation. The contribution (advisory and supportive) of the co-authors was kept within reasonable limits, thereby enabling the candidate to submit this dissertation for examination purposes. This dissertation, therefore, serves as fulfilment of the requirements for the degree Master of Health Sciences in Human Movement Sciences within PhASRec (Physical Activity, Sport and Recreation Focus Area), in the Faculty of Health Sciences at the North-West University (Potchefstroom Campus).

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“BE SOMEONE’S STRENGTH.

BE SOMEONE’S INSPIRATION.

BE SOMEONE’S REASON

TO NEVER GIVE UP”.

SUMMARY

Despite proof that diet may influence heart rate variability (HRV) and heart rate recovery (HRR)) as indicators of the autonomic nervous system (ANS) activation, no researchers have investigated the influence of a normal short-term in-competition diet on the real-life competition HRV and HRR of participants. Therefore, the objectives of this study were first, to determine the relationships between 24-hour diet and pre-, in-, and post-match HRV of badminton players; and, secondly, to determine the relationships between a 24-hour diet and the in- and post-match HRR of badminton players.

To fulfil the above-mentioned objectives, the HRV and HRR of 22 male, African, singles badminton players (age: 23.3 ± 3.9 years; height: 177.1 ± 3.0 cm; mass: 83.4 ± 14.5 kg) were measured before, during, and directly after 46 badminton matches using fixed Polar HR transmitter belts and monitors. A 24-hour diet recall questionnaire in an interview format was used to estimate the dietary intake of participants' normal in-competition days. Results of cluster analyses reduced diet-related variables were canonically correlated to the pre-match, in-match, and post-match HRV as well as in-match and post-match HRR parameters of participants. The level of significance was set at $p \leq 0.05$.

For the first objective of the study, canonical correlations of the respective relationships between the macronutrient, micronutrient, and HRV parameters over the different match periods, showed significant values ($p = 0.0000-0.03$), except for the canonical correlation ($R_c = 0.97$, $p = 0.105$) between the 24-hour in-competition macronutrient intake and the post-match HRV-related variables of the badminton players. Results further revealed that trans-fatty acids and available carbohydrates (CHO) were the macronutrients that had the greatest influence on changes in HRV parameters over the different match periods. In addition, calcium, potassium, vitamin D, and boron were identified as the micronutrients with the biggest influence on changes in participants' pre-match HRV. Calcium was the only micronutrient that had a meaningful influence on HRV changes during the in-match period, whereas potassium had the most influence on post-match HRV changes.

For the second objective of the study, the canonical correlation for the relationship between micronutrient components, and the in- and post-match HRR-related variables of participants

showed a significant value ($R = 0.92$ $p = 0.03$), whereas the relationship between macronutrients, and the in- and post-match HRR of participants were non-significant ($R = 0.84$, $p = 0.10$). Results further revealed that available CHO, total sugars, added sugars, as well as trans-fatty acids, were the macronutrients with the biggest influence on changes in HRR-related variables over the two match periods. Finally, vitamin D, calcium, and potassium were the micronutrients that contributed meaningfully to changes in participants' in- and post-match HRR.

To the knowledge of the researcher, this is the first study of its kind to investigate the influences of dietary intake on the parameters of ANS during a real-life badminton competition. Study results showed that badminton players' HRV and HRR during different periods of a real-life badminton competition were influenced by the intake of various diet components (macro and micronutrients). Therefore, the results highlight the importance of managing athletes' in-competition diets to ensure optimal functioning of the ANS during competition participation.

Keywords: autonomic nervous system, heart rate variability, heart rate recovery, badminton players, short-term diet, match play

OPSOMMING

Ten spyte van die bewyse dat dieet harttempoveranderlikheid (HTV) en harttempoherstel (HTH) as aanwysers van outonome senuweesisteem (OS)-aktivering, kan beïnvloed, het geen navorsers die invloed van 'n normale in-kompetisie, korttermyn-dieet op die werklike kompetisie HTV en HTH van deelnemers ondersoek nie. Daarom was die doelwitte van hierdie studie, ten eerste om die verbande tussen 'n 24-uur dieet en die voor-, in- en na-wedstryd-HTV van pluimbalspelers te bepaal; en tweedens om die verband tussen 'n 24-uur-dieet en die in- en na-wedstryd HTH van pluimbalspelers te bepaal.

Om die bogenoemde doelwitte te bereik, is die HTV en HTH van 22 manlike, Afrika-enkelspel pluimbalspelers (ouderdom: 23.3 ± 3.9 jaar; lengte: 177.1 ± 3.0 cm; massa: 83.4 ± 14.5 kg) gemeet tydens voor, in, en direk na 46 pluimbalwedstryde met behulp van vaste Polar harttempo-sendergordels en -monitors. 'n Vier-en-twintig-uur dieëtherroepingsvraelys in 'n onderhoudsformaat is gebruik om die dieëtinname van deelnemers se normale in-kompetisie dae te bepaal. Resultate van trosontleding-verminderde dieëtverbandhoudende veranderlikes is kanonies gekorreleer met die voor-, in- en na-wedstryd HTV sowel as in- en die na-wedstryd HTH-veranderlikes van deelnemers. Die vlak van betekenisvolheid is op $p \leq 0.05$ gestel.

Vir die eerste doelwit van hierdie studie, het kanoniese korrelasies vir die onderskeie verbande tussen die makrovoedingstof-, mikrovoedingstof- en HTV-veranderlikes oor verskillende wedstryd-periodes, betekenisvolle waardes getoon ($p = 0.0000-0.03$), behalwe vir die kanoniese korrelasie ($R_c = 0.97$, $p = 0.105$) tussen die 24-uur-inname van makrovoedingstowwe en die post-wedstryd HTV-veranderlikes van die pluimbalspelers. Resultate het verder aangedui dat transvetsure en beskikbare koolhidrate (CHO) die makrovoedingstowwe was wat die grootste invloed op die veranderinge in HTV-veranderlikes gedurende die verskillende wedstrydperiodes gehad het. Daarbenewens is kalsium, kalium, vitamien D en boor geïdentifiseer as die mikrovoedingstowwe wat die grootste invloed gehad het op veranderinge in deelnemers se HTV tydens die voor-wedstryd periodes. Kalsium was die enigste mikrovoedingstof wat 'n betekenisvolle invloed op HTV-veranderinge gedurende die in-wedstrydperiode gehad het, terwyl kalium die grootste invloed gehad het op HTV-veranderinge na die wedstryd.

Vir die tweede doelwit van hierdie studie, het die kanoniese korrelasie vir die verband tussen mikrovoedingstof-komponente en die in- en na-wedstryd HTH-verwante veranderlikes van deelnemers 'n betekenisvolle waarde getoon ($R = 0.92$ $p = 0.03$), terwyl die verband tussen makrovoedingstof-komponente en die HTH tydens die in- en na-wedstryd periodes van deelnemers, nie-betekenisvolle resultate getoon het nie ($R = 0.84$, $p = 0.10$). Resultate het verder aangedui dat beskikbare CHO, totale suikers, bygevoegde suikers sowel as trans-vetsure die makrovoedingstowwe was wat die grootste invloed gehad het op veranderinge in HTH-verwante veranderlikes gedurende die twee wedstrydperiodes. Aan die ander kant was vitamien D, kalsium en kalium die mikrovoedingstowwe wat betekenisvol bygedra het tot die veranderinge van HTH gedurende die in- en na-wedstryd periodes.

Volgens die kennis van die navorser, is dit die eerste studie van sy soort wat die invloede van dieëtmofikasies op die parameters van OS tydens 'n werklike pluimbal-kompetisie ondersoek het. Studieresultate het getoon dat pluimbalspelers se HTV en HTH gedurende verskillende periodes van 'n werklike pluimbalkompetisie beïnvloed is deur die inname van verskillende dieëtkomponente (makro- en mikro-voedingstowwe). Die resultate van hierdie studie beklemtoon dus die belangrikheid daarvan om sportlui se in-kompetisie diete te bestuur om die optimale funksionering van die OS tydens kompetisiedeelname te verseker.

Sleutelterm: outonome senuweestelsel, harttempoveranderlikheid, harttempoherstel, pluimbalspelers, korttermyndieet, wedstrydspel

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LIST OF ABBREVIATIONS

24-hDRQ	24-Hour dietary recall questionnaire
ANS	Autonomic nervous system
AR	Autoregressive modelling
BPM	Beats per minute
CHO	Carbohydrate
CV	Coefficient of variation
DHA	Dietary history assessments
DR	Dietary records
ECG	Electrocardiograph
FFQ	Food frequency questionnaire
FFT	Fast Fourier transformation
HF	High frequency (0.15-0.40 Hz)
HF (Hz)	High frequency power expressed in hertz
HF%	High frequency relative power expressed as percentage
HFnu	High frequency component expressed in normalised units
HR	Heart rate
HRmax	Maximal heart rate
HRR	Heart rate recovery
HRV	Heart rate variability
HT	Highly trained
Hz	Hertz
IU	International units
LF	Low frequency (0.04-0.15 Hz)

LF (Hz)	Low frequency power expressed in hertz
LF%	Low frequency relative power expressed as percentage
LF/HF ratio	Low and high frequency components expressed as a ratio
LFnu	Low frequency component expressed in normalised units
Ln-HFnu	Natural logarithmic transformation of high frequency power expressed as normalised units
Ln-LFnu	Natural logarithmic transformation of low frequency power expressed as normalised units
Ln-LFnu/Ln-HFnu ratio	Ratio between Ln-LFnu and Ln-HFnu components
Ln-RMSSD	Natural logarithm transformation for the squared root of the mean squared differences between successive R-R intervals
Ln-RMSSD _{CV}	The natural logarithm of the coefficient of variation of square root of mean squared differences between successive R-R intervals
Ln-RMSSD _{mean}	The natural logarithm of the mean square root of mean squared differences between successive R-R intervals
Ln-SD1	Natural logarithm transformation for the standard deviation one
Ln-SD2	Natural logarithm transformation for the standard deviation two
Ln-SDNN	Natural logarithm transformation for the standard deviation of R-R intervals
MAS	Maximal aerobic speed
Mean R-R	Mean of R-R intervals in milliseconds
MT	Moderately trained
N-N intervals	Interbeat intervals between normal to normal heartbeats
Peak HF (Hz)	High band peak frequencies in hertz

Peak LF (Hz)	Low band peak frequencies in hertz
Peak VLF (Hz)	Very low band peak frequencies in hertz
PTN	Peri-training nutrition
pNN50	Proportion of consecutive R-R intervals that exceed 50 milliseconds
PNS	Parasympathetic nervous system
QRS signals	Electrical impulses flowing through ventricles which indicate ventricular depolarization
RMSSD	Squared root of the mean squared differences between successive R-R intervals
R-R intervals	Inter-beat intervals or R to R intervals
SA node	Sinoatrial node is the primary pacemaker within the heart
SD	Standard deviation
SD1	Standard deviation one
SD2	Standard deviation two
SD1/SD2	SD1 and SD2 expressed as a ratio
SDANN	Standard deviation of the averages of NN intervals in all 5-minutes segments of the entire recording
SDNN	Standard deviation of R-R intervals
SNS	Sympathetic nervous system
SV	Stroke volume
TP	Total power
VLF	Very low frequency (0.0033-0.04 Hz)
VLF (Hz)	Very low frequency relative power expressed in Hertz
VLF%	Very low frequency power expressed as percentage

$\text{VO}_{2\text{max}}$	Maximal oxygen uptake
$\text{VO}_{2\text{peak}}$	Peak oxygen uptake
Yo-Yo IR1	Yo-Yo Intermittent Recovery Test One

CHAPTER 1: INTRODUCTION

1.1 PROBLEM STATEMENT

Even though the diet of an athlete has the power to influence autonomic nervous system (ANS) functioning during competition participation (Clarke & Duncan, 2016:108), few researchers have focused their attention on the possible influence of diet on ANS parameters (Havemann *et al.*, 2006; Lima-Silva *et al.*, 2010a; Lima-Silva *et al.*, 2010b). Heart rate variability (HRV) is regarded to be a trustworthy, non-invasive parameter for evaluating the ANS activity of sport participants since the ANS plays an essential role in regulating the cardiovascular system during sports participation (Aubert *et al.*, 2003:890; Figueiredo *et al.*, 2019:1223; Vanderlei *et al.*, 2009:213). HRV is the variation in time between consecutive heartbeats or R-to-R intervals, where R-to-R intervals are defined as the duration between two adjacent R-peaks in the QRS complex (electrical impulses that indicate ventricular depolarisation) of the electrocardiogram (ECG) wave (Bellenger *et al.*, 2016:1462; Perry *et al.*, 2019:43; Sharma *et al.*, 2015:641). Research evidence suggests that higher intensities during sports participation lead to an increased sympathetic modulation as indicated by increases in the HRV parameters of the sympathetic nervous system (SNS) in cyclists, triathletes, and distance runners (Hottenrott *et al.*, 2006:546; Makivic *et al.*, 2013:126). Another standard measure of autonomic heart rate (HR) regulation, namely post-exercise HRR, reflects the coordinated interaction between parasympathetic re-activation and sympathetic withdrawal after exercise (Bellenger *et al.*, 2016:1462). Both HRV and HRR values are used as indicators of training status and sport performance and allow researchers to interpret cardiac autonomic regulation in sport and exercise settings (Seiler *et al.*, 2007:1370). However, until now, few researchers have investigated autonomic markers of HR during and after a live sports event (Douglas *et al.*, 2016; Hernández-Cruz *et al.*, 2017). Furthermore, despite proof that ANS function is influenced by short-term (24-hour) diet, only a limited number of studies have investigated the possible influence of diet on ANS control (Havemann *et al.*, 2006; Lima-Silva *et al.*, 2010a; Lima-Silva *et al.*, 2010b).

In badminton specifically, the physiological load placed upon players is extremely high, which increases the fatigue levels and energy demands of athletes (Clarke & Duncan, 2016:108). For example, studies found that players normally operate at an average HR that is higher than 90% of the maximum HR during match-play (Alder *et al.*, 2019:1817; Phomsoupha & Laffaye, 2015:474). Researchers can only determine an athlete's fatigue level and his/her need for recovery if the body's stress response after different intensities of physical activity is established (Buchheit, 2014:15; Castrillón *et al.*, 2016:470; Thorpe *et al.*, 2016:947). HRV is a measure that can be used to determine

the body's stress response to exercise because different HRV parameters serve as indicators of SNS and parasympathetic nervous system (PNS) activity (Buchheit, 2014:1; Cunha *et al.*, 2015:100; Goldberger *et al.*, 2006:2446). The SNS leads to elevated HR, stroke volume (SV), and a decrease in HRV, while the PNS leads to decreases in HR and SV, but an increase in the overall HRV (McArdle *et al.*, 2015:327, 330; Tarvainen *et al.*, 2014:210). The PNS is more dominant during rest periods, while the activity of the SNS increases during physical activity (Javorka *et al.*, 2002:997).

In this regard, Bricout *et al.* (2010:115) indicated that soccer match play led to a significant increase in low-frequency power (LF) to high-frequency power (HF) ratio, due to a significant decrease in PNS stimulation. Douglas *et al.* (2016:482) found a significant reduction in the mean squared differences between successive R-R intervals (RMSSD) after a rugby sevens match. They concluded that the reduction in PNS activity, as indicated by the decrease in RMSSD, was caused by a strong SNS response during match play (Douglas *et al.*, 2016:482). The last-mentioned researchers further indicated that a greater resting parasympathetic modulation benefits the peak-HR response by allowing for a fast parasympathetic withdrawal at the onset of exercise (Douglas *et al.*, 2016:486). This fast parasympathetic withdrawal, in combination with the extreme drive in sympathetic activity, function as modulators of stress vulnerability and the reactive capacity of the ANS (Douglas *et al.*, 2016:486). In a more recent study, volleyball players experienced significant decreases in standard deviation of all normal-to-normal intervals (SDNN), RMSSD, the percentage of consecutive N-N intervals that differ by more than 50 milliseconds (pNN50) and standard deviation of instantaneous beat-to-beat interval variability (SD1) from baseline values over the course of two matches (Hernández-Cruz *et al.*, 2017:11). These results suggest that activities that lead to strong SNS responses will significantly reduce PNS activity for a limited time after exercise (Bricout *et al.*, 2010:112, 115; Douglas *et al.*, 2016:482; Hernández-Cruz *et al.*, 2017:11).

Although both HRV and HRR are considered to be indicators of ANS function, several researchers found no relationship between them, which may indicate that these variables are independently linked to the ANS (Bosquet *et al.*, 2007:367). The dissociation between HRR and resting HRV has compelled researchers to also investigate HRR as an independent ANS parameter (Esco *et al.*, 2010:36). Heart rate recovery (HRR) serves as a valuable non-invasive parameter to evaluate the cardiovascular-parasympathetic system and the current condition of the ANS after exercise (Borresen & Lambert, 2007:504; Esco *et al.*, 2010:36). For example, the HRR of well-trained cyclists improved after four weeks of high-intensity training and these improvements correlated significantly with increased cycling performance (Harry & Booyesen, 2019; Lamberts *et al.*,

2009:709, 710). Furthermore, Gocentas *et al.* (2011:14) confirmed that cardiac autonomic control of the fittest players in an elite basketball team improved the most throughout the season as these players' HR recovered the fastest after sport-specific exercises. In contrast, players who were classified as less fit displayed an ascending trend with regards to HRR after sport-specific exercise (Gocentas *et al.*, 2011:14).

Although existing research reported on the changes in different HRR and HRV parameters as indicators of ANS activity during sports participation, the above-mentioned parameters seem to be influenced by various factors such as 24-hour (short-term) diet (Clarke & Duncan, 2016:108). The last-mentioned type of diets can be classified into three categories based on the CHO content of each. These are: low-CHO diets = <26%; moderate-CHO diets = 26%-45% and high-CHO diets = >45% (Ahn *et al.*, 2019:2025). A few researchers have investigated the influence of different classifications of CHO-containing diets on functioning of the ANS. In this regard, a low-carbohydrate (CHO), high-fat diet caused an increase in pre-exercise LF power of endurance cyclists, which is suggestive of increased sympathetic activation (Havemann *et al.*, 2006:200). Lima-Silva *et al.* (2010b:1137) showed that a short-term low-carbohydrate diet (10% of total energy from carbohydrates) leads to significantly higher SD1 values at exhaustion during a severe-intensity cycling exercise as compared to a high-carbohydrate diet (65% of total energy from carbohydrates). After the severe-intensity exercise was performed the participants rested for 5 minutes and showed significantly higher standard deviation of continuous long-term beat-to-beat interval variability (SD2) values in the low- compared to the high-carbohydrate diet group (Lima-Silva *et al.*, 2010b:1137). In addition, the short-term, low-carbohydrate diet caused significantly higher HF and LF scores at exhaustion than the high-carbohydrate diet (Lima-Silva *et al.*, 2010b:1137). On the other hand, studies have also shown that certain mineral and vitamins, such as vitamin D, calcium, and dietary sodium can influence ANS functioning (Allen *et al.*, 2014:380; Tønnesen *et al.*, 2018:7). For example, the intake of these micronutrients caused an increase in healthy participants' SNS activity and a consequent rise in blood pressure and HR (Allen *et al.*, 2014:380; Tønnesen *et al.*, 2018:7). These latter results provide evidence that sympathetic and parasympathetic outflow is alternated in response to dietary manipulation, supporting the notion that sympathetic activity during severe-intensity exercise and parasympathetic activity during rest can be influenced by low-carbohydrate (CHO) availability (Lima-Silva *et al.*, 2010a:542; Lima-Silva *et al.*, 2010b:1138).

Most studies have used laboratory-based tests or simulated matches to determine the HRV and HRR of participants instead of real-life competitions (Arai *et al.*, 1989:132; Casadei *et al.*, 1995:125;

Dobbs *et al.*, 2019:420; Tulppo *et al.*, 1998:425). Therefore, researchers need to keep in mind that the high pressure of competition participation will automatically bring about sympathetic predominance (D'Ascenzi *et al.*, 2014:230; Flatt *et al.*, 2019:619; Garrido-Esquivel *et al.*, 2011:257), which may influence the trends in HRV and HRR changes during competition participation. Furthermore, despite proof that diet may influence ANS control, only a limited number of researchers have investigated this influence (Havemann *et al.*, 2006; Lima-Silva *et al.*, 2010a; Lima-Silva *et al.*, 2010b). It is in light of this background and the shortcomings in existing research that the following two research questions are posed: Firstly, what are the relationships between 24-hour diet and pre-, in-, and post-match HRV of badminton players? Secondly, what are the relationships between 24-hour diet and the in- and post-match HRR of badminton players? Answers to these questions should enable researchers to better understand the possible effects of a short-term diet on the ANS of players during sport participation. Furthermore, answers should provide sport practitioners with more information regarding the type and composition of short-term diets that will have the biggest effect on ANS regulation during sports participation.

1.2 OBJECTIVES

The objectives of this study were to determine:

- Relationships between 24-hour diet and pre-, in-, and post-match HRV of badminton players.
- Relationships between 24-hour diet and the in- and post-match HRR of badminton players.

1.3 HYPOTHESES

This study is based on the following hypotheses:

- A 24-hour low CHO diet will lead to significantly higher SNS-related pre-, in-, and post-match HRV (very low band peak frequencies in hertz (Peak VLF Hz), VLF relative power expressed as a percentage (VLF%), low band peak frequencies in hertz (Peak LF Hz), LF relative power expressed as a percentage (LF%), and the natural logarithmic transformation of the standard deviation 2 (Ln-SD2)) values of badminton players compared to a high-CHO diet. Furthermore, a 24-hour low-CHO diet will lead to significantly lower PNS-related pre-, in-, and post-match HRV (high band peak frequencies in hertz (Peak HF Hz), HF relative power expressed as a percentage (HF%), the natural logarithmic transformation of HF relative power expressed as normalised units (Ln-HFnu), SDNN, the natural logarithmic transformation (Ln) of RMSSD, and the mean of R-R intervals in milliseconds (Mean R-R) and SD1) values of badminton players compared to a high-CHO diet.

- A 24-hour diet that contains less mineral- and vitamin-related components will lead to significantly higher SNS-related pre-, in-, and post-match HRV (Peak VLF Hz, VLF%, Peak LF Hz, LF%, and Ln-SD2) values of badminton players than a diet containing more mineral and vitamin-related components. Furthermore, a 24-hour diet with less mineral and vitamin-related components will lead to significantly lower PNS-related pre-, in-, and post-match HRV (Peak HF Hz, HF%, Ln-HFnu, SDNN, Ln-RMSSD, Mean R-R, and SD1) values of badminton players than a diet that contains more mineral and vitamin-related components.
- A 24-hour low-CHO diet will lead to significantly lower HRR values of badminton players compared to a high-CHO diet.
- A 24-hour diet that contains more mineral- and vitamin-related components will lead to significantly higher in- and post-match HRR values of badminton players than a diet containing less mineral and vitamin-related components.

1.4 STRUCTURE OF DISSERTATION

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

Chapter 1: Introduction.

Chapter 2: Literature review: Relationship between diet and autonomic markers of heart rate in sport participants.

Chapter 3: Article 1: Relationships between 24-hour diet and pre-, in-, and post-match heart rate variability of badminton players. This article was submitted to the *Journal of Strength and Conditioning Research*. This chapter and reference list at the end of the chapter was compiled according to the guidelines of the last-mentioned journal. Although not according to the journal requirements, tables will be included in this article to make the article understandable and easier to read. Also, the line spacing of the article will be set as 1.5 lines. Since this article was submitted to an American-based journal, the proofing language was set to United States English.

Chapter 4: Article 2: Relationships between 24-hour diet and the in- and post-match heart rate recovery of badminton players. This article was submitted to the *International Journal of Sports Medicine*. This chapter and reference list at the end of the chapter was compiled according to the guidelines of the last-mentioned journal. Although not according to the journal requirements, tables will be included in the article to make the article understandable and easier to read. Also, the line spacing of the article will be set

as 1.5 lines. Since this article was submitted to a European-based journal, the proofing language was set to United Kingdom English.

Chapter 5: Summary, conclusions, limitations, and recommendations.

1.5 CONTRIBUTIONS OF RESEARCH TEAM MEMBERS

The following table includes the members of the research team involved in the compilation of this master degree dissertation and also indicates the contribution of each member involved.

Table 1.1: Members involved in the research team

Name and surname	Qualification	Role and responsibility
Mr Pierre Bonthuys	Hons Sport Science	MSc Sport Science student Data search, data extraction, statistical analysis and writing of protocol and review as well as writing of the dissertation.
Prof Ben Coetzee	Assoc. Prof. Sport Science	Supervisor Provided expert advice on HRV, HRR and ANS control. Critically appraised the data extracted and gave assistance in the writing of the protocol, review, statistical analysis as well as the writing of the dissertation.
Dr Christo Bisschoff	PhD Sport Science	Co-Supervisor Assistance and guidance with data searches regarding HRV and HRR in sport and exercise. Critically appraised the data extracted and gave support in revising the dissertation.

Table 1.1 (cont.): Members involved in the research team

Name and surname	Qualification	Role and responsibility
Dr Chrisna Botha-Ravyse	PhD Dietetics	Assistant-Supervisor Critically appraised the data extracted and gave support in the writing of the dietary information and interpretation of the dietary data as well as revising the dissertation.

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CHAPTER 2: LITERATURE REVIEW – RELATIONSHIPS BETWEEN DIET AND THE AUTONOMIC MARKERS OF HEART RATE IN PARTICIPANTS

2.1 INTRODUCTION

In recent years, there has been a growing interest in the functioning of the autonomic nervous system (ANS) during sport and exercise because of its importance in determining the stress response of the body during such activities (Buchheit, 2014:72 Suetake & Kobayashi, 2017:83). The ANS is responsible for the functioning of the vital functions in the body such as heart rate (HR), blood pressure, digestive and urinary processes (Amerman, 2016:559; Liu *et al.*, 2020:1). The control of the cardiac system, via the ANS, can be gauged by measuring heart rate variability (HRV) and heart rate recovery (HRR) (Borresen & Lambert, 2008:634). Heart rate variability (HRV) can be defined as the variation in the time between consecutive heart beats or beat-to-beat intervals as the time between each cardiac cycle elapses (Armstrong *et al.*, 2012:501; Bellenger *et al.*, 2016:1462; Perry *et al.*, 2019:43). Furthermore, HRV serves as an indicator of ANS functioning through the activation of the sympathetic nervous system (SNS) and parasympathetic nervous system (PNS) (Dong, 2016:1531). The SNS is important for HR functioning as it elevates HR and stroke volume (SV) and reduces HRV during exercise (McArdle *et al.*, 2015:327, 330; Tarvainen *et al.*, 2014:210). In contrast, the PNS leads to decreases in HR and SV, and an increase in overall HRV during rest periods (McArdle *et al.*, 2015:327, 330; Tarvainen *et al.*, 2014:210). Another standard measurement of autonomic HR control, namely HRR or post-exercise HRR, serves as an important indicator of PNS activation, especially after exercise and sport participation (Borresen & Lambert, 2007:504; Esco *et al.*, 2010:36). Therefore, HRR is the decrease of HR after exercise and reflects the coordinated interaction between parasympathetic reactivation and sympathetic withdrawal (Bellenger *et al.*, 2016:1462; Van de Vegte *et al.*, 2018:1). The last-mentioned parameters of ANS activation (HRV and HRR) provide meaningful information to sport scientists, coaches, and researchers regarding the functional adaptations of the body during sports participation (Borresen & Lambert, 2008:634; Liu *et al.*, 2020:1; Seiler *et al.*, 2007:1370). However, until now, only a small number of researchers have investigated the autonomic markers of HR in athletes during and after live sport events (Douglas *et al.*, 2016; Flatt *et al.*, 2019:619; Hernández-Cruz *et al.*, 2017:13).

The ANS is classified as an autonomously operating system that functions without conscious control and performs actions through a series of visceral reflex arcs (Amerman, 2015:559). Furthermore, it is divided into two subdivisions, either neurons or branches, namely sympathetic and

parasympathetic branches (McArdle *et al.*, 2015:391), which differ from each other anatomically and physiologically. In addition, they are independently linked to each other during certain functions but cooperatively dependant on each other during other functions (McArdle *et al.*, 2015:391). Monitoring of the ANS branches through HRV shows that PNS reactivation is impaired by repeated sprint exercise, while SNS activation is stimulated (Buchheit, 2014:84). In this regard, several researchers have observed a significant reduction in PNS activity after match play and attributed this to the strong SNS response, which occurs during match play (Douglas *et al.*, 2016:482). Despite the availability of several studies that have investigated HRV and HRR during live sports events, the majority of researchers do not consider variables such as diet when evaluating the ANS-related parameters of athletes during sports participation (Flatt *et al.*, 2019; Garrido-Esquivel *et al.*, 2011; Gocentas *et al.*, 2011). While research has revealed that sympathetic activity during severe-intensity exercise and parasympathetic activity during rest can be influenced by dietary availability and composition (Lima-Silva *et al.*, 2010a:542; Lima-Silva *et al.*, 2010b:1138), only a limited number of researchers have, to-date, investigated the possible influence of diet on ANS control (Havemann *et al.*, 2006; Lima-Silva *et al.*, 2010a; Lima-Silva *et al.*, 2010b).

In view of this background and lack of ANS research regarding changes in HRV and HRR during and after live sports events, as well as the possible influence of diet on the last-mentioned variables, the objectives of this literature review were to: firstly, discuss the functioning of the ANS and the physiological mechanisms that underlie cardiac control through the different branches of the ANS; secondly, indicate, define, and discuss the different parameters of HRV as well as the meaning of each; thirdly, indicate, define, and discuss HRR as an ANS-related parameter; fourthly, discuss the protocols that are used to measure and determine HRV and HRR; fifthly, discuss previous studies that have investigated the use of HRV and HRR in exercise and sport settings; sixthly, highlight the possible influence of a 24-hour (short-term) diet on HRV and HRR during sport participation; seventhly, discuss the protocols and questionnaires that are used to determine various components of a particular short-term diet. Finally, indicate and discuss limitations of current research that have investigated the use of HRV and HRR in an exercise or sport setting as well as research that focused on the influence of short-term diet on HRV and/or HRR.

Studies that have incorporated HRV and HRR in a clinical setting were excluded from this review since it only focused on recent studies that have investigated HRV and HRR (2006 to 2020) in exercise and sport settings; however, older pivotal studies were used to define the methodology of HRV components (studies from 1995 to 2003). Furthermore, only research that published in English

and after 2006 was selected for use in this review. Moreover, it primarily targeted studies that made use of athletes or physically active participants with no exclusion criteria set for age, gender, and population size. The search engines and databases that were used to gather information for the literature review are Google Scholar, Sport Discus, Science Direct, and EDS Search, which made it possible for authors to refer to several journals, websites, exercise, and physiology textbooks. The last-mentioned sources were used to search for the following keywords: Autonomic nervous system (ANS), heart rate variability (HRV), heart rate recovery (HRR), performance, diet, nutrition, sport setting, team sports, match play, R-R intervals, and Polar HR monitors.

In the following section, the ANS functioning and the physiological mechanisms that underlie cardiac control will be discussed.

2.2 AUTONOMIC NERVOUS SYSTEM FUNCTIONING AND THE PHYSIOLOGICAL MECHANISMS THAT UNDERLIE CARDIAC CONTROL THROUGH THE DIFFERENT BRANCHES OF THE AUTONOMIC NERVOUS SYSTEM

As previously mentioned, the sport performance of athletes is influenced by the functioning of the ANS (Chalencon *et al.*, 2015:595). However, the ANS forms part of the central nervous system, which is responsible for regulating many visceral bodily functions, including, HR, blood pressure, digestive, and urinary processes, body temperature, and basal metabolism (Amerman, 2016:559; Liu *et al.*, 2020:1). Since the cardiovascular system is also regulated by the ANS, the monitoring of this system during sports participation is very important (Makivic *et al.*, 2013:108). To understand the vital role of the ANS, the functioning of HRV and HRR parameters and their close association with sport performance, the physiological mechanisms of this system will first be explained.

2.2.1 Physiological mechanisms of cardiac control

The ANS originates within the cranial and peripheral nerves, which are strongly associated with the peripheral and the central nervous system (Rhoades & Bell, 2013:113, 115). The peripheral nervous system includes the somatic, as well as the ANS (Hall, 2015:773). The ANS is activated through the spinal cord, brainstem, and hypothalamus, which are responsible for the transmission of signals to influence autonomic control (McArdle *et al.*, 2015:327, 328). It is very efficient, as it can double the pulse rate from its normal rate in less than 5 seconds and can double the arterial pressure value within 10-15 seconds (Hall, 2015:773). The efferent autonomic signals are influenced by two major subdivisions, namely the SNS and PNS (Hall, 2015:773; McArdle *et al.*, 2015:328). The SNS is associated with the fight-or-flight response and the PNS is referred to as the rest-and-digest system

(McArdle *et al.*, 2015:328). In this regard, neural signals influence changes in HR tempo, which originates from the cardiovascular control centre found in the ventrolateral medulla (Makivic *et al.* 2013:106). These signals travel through different SNS and PNS pathways that bring about the desired HR response (Hall, 2015:773). While the SNS consists of chronotropic and inotropic reactions that increase SA node depolarisation (chronotype) and myocardial contractility (inotropic) of the heart through the sympathetic cardio-accelerator nerves that release neuro-hormones, such as epinephrine and norepinephrine (Kenney *et al.*, 2011:74), the PNS causes bradycardia through the release of acetylcholine (Hall, 2015:773). However, both systems innervate the heart and regulate HR functioning, together with central processes, neuroendocrine functions, and reflex arcs (Grippio, 2017:1; Makivic *et al.* 2013:105; McArdle *et al.*, 2015:328). Lastly, PNS reactivation is impaired during high-intensity exercise, whereas SNS activation is stimulated during these situations (McArdle *et al.*, 2015:327, 330; Tarvainen *et al.*, 2014:210).

In the following section, the different parameters of HRV will be defined and discussed.

2.3 HEART RATE VARIABILITY AS AN AUTONOMIC NERVOUS SYSTEM-RELATED PARAMETER

Heart rate variability (HRV) is a non-invasive, pain-free, economic, and simple measure that is commonly used by many researchers, and can be obtained from electrocardiogram (ECG) signals (Coelho *et al.*, 2019:3; Dong, 2016:1532; Flatt *et al.*, 2019:616; Laborde *et al.*, 2017:2). It reflects the health and physical wellbeing of an individual since it provides information concerning the interaction between the activation of the SNS and PNS (Makivic *et al.* 2013:108). Therefore, the measurement of HRV will enable researchers to obtain meaningful information concerning the functioning of the ANS during sport and exercise participation (Grippio, 2017:1; Makivic *et al.* 2013:105).

2.3.1 Different parameters of heart rate variability

Heart rate variability (HRV) parameters can be divided into three main categories, namely time, frequency, and non-linear domain, HRV-related parameters (Makivic *et al.* 2013:110; Task Force, 1996a:355).

2.3.1.1 Time-domain heart rate variability parameters

The most frequently used time-domain HRV parameters in sport and exercise are mean R-R (interbeat intervals between successive heartbeats) intervals, the standard deviation (SD) 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 percentage of consecutive N-N intervals (interbeat intervals from which artefacts have been removed) that differ by more than 50 milliseconds (pNN50) (Aubert *et al.* 2003:892; Buchheit, 2014:80). The mean R-R intervals are calculated by determining the time that elapses between two successive R-R waves of QRS signals (electrical impulses flowing through ventricles which indicate ventricular depolarisation) (Makivic *et al.*, 2013:106). Autonomic influences are controlled through the sinus node which determines the mean R-R intervals (Richig & Sleeper, 2018:59). At the onset of exercise, an increased sympathetic drive allows for faster parasympathetic withdrawal and this is indicated by shorter and less varied mean R-R intervals (Makivic *et al.* 2013:110). The variation in R-R intervals during and after physical exercise is examined by researchers, as it provides meaningful insight into physiological stress and fatigue levels in athletes (Douglas *et al.*, 2016:486; Makivic *et al.* 2013:110).

N-N intervals also represent R-R intervals, but with added filtering, which helps to remove artefacts and noise in data sets (Richig & Sleeper, 2018:43). The standard deviation of R-R intervals in milliseconds (SDNN) represents the total variability of cardiac autonomic activity, which is significantly influenced by the duration of measurements (Aubert *et al.* 2003:894; Makivic *et al.* 2013:107). The SDNN is a very fragile parameter, as it is especially influenced by factors that affect long-term circulatory variability, such as circadian rhythms (Sztajzel, 2004:516). Time-domain parameters, such as SDNN, reflect the SD of all adjacent N-N intervals (Makivic *et al.* 2013:107). This parameter is associated with high-frequency (HF)-related components that serve as measurements of parasympathetic activity (Makivic *et al.* 2013:107). However, a decrease in the SDNN parameter reflects lower PNS activity, which indicates a change in the ANS balance (Makivic *et al.* 2013:105; Plews *et al.*, 2013:775). The RMSSD serves as very accurate measure of ultra-short-term HRV (less than 60 seconds), due to its accuracy and low coefficient of variation, especially in sport and exercise settings (Buchheit, 2014:81; Plews *et al.*, 2013:775). Furthermore, this measurement is also considered more stable compared to all other domain parameters during parasympathetic activity, due to a distinct lack of sensitivity to breathing frequency (Plews *et al.*, 2013:775). The previously mentioned HRV time-domain parameter, namely pNN50, is very similar to RMSSD, as it also represents parasympathetic activity (Aubert *et al.* 2003:895; Task Force, 1996a:357). However, pNN50 is often dismissed as this parameter normally achieves very low values in the normal population. Therefore, researchers rather make use of RMSSD, as this parameter delivers more consistent and accurate values which reflects PNS activity (Aubert *et al.* 2003:895; Task Force, 1996a:357).

Consequently, time-domain parameters consist of the following HRV-related parameters:

- The mean of R-R intervals in milliseconds (mean R-R);
- 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;
- Lastly, the percentage of consecutive N-N intervals that differ by more than 50 milliseconds (pNN50).

The above-mentioned time-domain parameters (mean R-R, SDNN, RMSSD, pNN50) can be calculated during short and long time periods, by applying mathematical and algorithmic models (Makivic *et al.* 2013:110). Despite the difficulty of using mathematical and algorithmic models to obtain different parameters, measurements of HRV can also be obtained by using wristwatch monitors (e.g. Polar, Suunto, and Apple) and portable devices (manufactured by Omegawave Sport Technology Systems) combined with several software packages (e.g. Polar Team² Pro, Polar Electro, Kempele, Finland) (Makivic *et al.* 2013:110).

2.3.1.2 Frequency-domain heart rate variability parameters

Frequency-domain HRV parameters are more difficult to determine than the time-domain parameters, displaying both high and low-frequency rates of variability changes, which are linked to the activity of different ANS branches (Makivic *et al.* 2013:107). Frequency-domain parameters are computable by performing a spectral analysis on R-R intervals (Buchheit, 2014:81; Archarya *et al.*, 2006:1037, 1038); a type of analysis that converts the data set of R-R intervals to a sinusoidal form, which also allow the extraction of multiple waves at different frequencies from the one biological signal (Aubert *et al.*, 2003:893-896). The application of the fast Fourier transformation (FFT) or autoregressive modelling (AR) allows researchers to plot the sinusoidal components of R-R intervals (Tarvainen *et al.*, 2014:212). These particular techniques (FFT and AR) provide researchers with new sets of R-R intervals for humans only, which can be divided into three commonly used peak and power frequency categories, namely the very-low-frequency band (VLF = frequency between 0.0033-0.04 Hz), the low-frequency band (LF = frequency between 0.04-0.15 Hz), and the high-frequency band (HF = frequency between 0.15–0.40 Hz) components (Taelman *et al.*, 2009:1367; Tarvainen & Niskanen, 2012:20; Shaffer & Ginsberg, 2017:5).

In addition, by utilising them, researchers are able to measure frequency components in the form of absolute powers (ms^2), relative powers (%), and normalised powers (normalised units), respectively

(Tarvainen & Niskanen, 2012:20). As a result, absolute power (ms^2) is calculated as milliseconds squared divided by the number of cycles per second (ms^2/Hz) (Shaffer & Ginsberg, 2017:2), whereas, relative power (%) is determined as the percentage of total HRV power, or as the normal units, which separates the absolute powers into a certain frequency band category by the summed absolute power of LF and HF components (Shaffer & Ginsberg, 2017:2). This allows the user to compare frequency-domain parameters of two individuals regardless of the wide variation in band power and total power between healthy, age-matched individuals (Shaffer & Ginsberg, 2017:2). In addition, normalised powers are measured by the raw R-R intervals obtained during short-term frequency components ($\text{LFnu \%} = \text{LF}/(\text{LF}+\text{HF})$ or $\text{LF}/(\text{total power (TP)}-\text{VLF})$), which is divided by the total spectral power with a value that is either expressed as a percentage or a decimal (Heathers, 2014:3).

The above-mentioned information shows that researchers can successfully obtain different frequency-domain parameters that either represent sympathetic (LF) or parasympathetic (vagal) activity (HF) (Makivic *et al.* 2013:110). Low frequency (LF) is occasionally associated with the SNS (during exercise), and especially with the PNS (during rest), whereas HF only represents PNS activity (Lewis *et al.*, 2007:35; Martinmaki *et al.*, 2008:546). Low frequency (LF) and HF parameters are also expressed as ratios (LF/HF), which indicates sympathovagal balance (Lewis *et al.*, 2007:35; Lopes & White, 2006:41; Makivic *et al.* 2013:110; Reyes del Paso *et al.*, 2013:483). In this regard, researchers observed an increase in the LF/HF ratio during low-intensity exercise and attributed this to the coordinated interaction between parasympathetic withdrawal and an increase in sympathetic activity (Aubert *et al.*, 2003:901; Lewis *et al.*, 2007:35). Another frequency-domain parameter that researchers use is the VLF and can be associated with sympathovagal balance (Usui & Nishida, 2017:2). However, VLF is a very complex measure which is influenced by several factors, which include the chemoreflex activity, thermal entrainment, PNS as well as SNS activity as well as noise (Shaffer & Ginsberg, 2017:5). The VLF values seem to be generated by the activation of afferent sensory neurons in the cardiac muscle (Shaffer & Ginsberg, 2017:5). Therefore, the intrinsic network of the heart seems to contribute to the VLF rhythms, through which the SNS influences the amplitude and frequency of its oscillations (Shaffer & Ginsberg, 2017:5). The PNS activity is also likely to contribute to VLF power since parasympathetic blockade (atropine) nearly eliminates the effect of this parameter (Shaffer & Ginsberg, 2017:5; Taylor *et al.*, 1998:550). One last frequency domain-related parameter that can be used when evaluating HRV is the total power, which is calculated as the sum of energy for the VLF, LF, and HF components over 5 minute segments, monitored during a 24-hour period (Shaffer & Ginsberg, 2017:2; Shaffer *et al.*,

2014:13). Occasionally, the total power of a complete spectral analysis is used to evaluate the overall variability of R-R intervals (Cipryan *et al.*, 2007:18; Task force, 1996a:360).

Consequently, frequency-domain parameters consist of the following HRV parameters:

- Very low band peak frequencies in hertz (Peak VLF Hz);
- Low band peak frequencies in hertz (Peak LF Hz);
- High band peak frequencies in hertz (Peak HF Hz);
- VLF relative power expressed as a percentage (VLF%);
- LF relative power expressed as a percentage (LF%);
- HF relative power expressed as a percentage (HF%);
- The ratio between LF and HF components (LF/HF ratio); and,
- Total power of complete spectral analysis (TP).

2.3.1.3 Non-linear heart rate variability parameters

Non-linear-related HRV parameters are the most complicated of all three categories of HRV parameters to determine, as the chaotic nature of beat-to-beat variability requires a powerful computing method such as the Poincare plot method (Tarvainen *et al.*, 2014:212). Poincare is one of several methods that allow researchers to indicate the non-linear dynamics of R-R intervals, which reveal the fluctuations in R-R intervals (Buchheit, 2014:75; Aubert *et al.*, 2003:898). When it is applied to non-linear components, each interval gets plotted as a function of the previous R-R interval (Tarvainen *et al.*, 2014:212). Once these actions have been performed, the plot can be analysed quantitatively, by calculating the SDs of correlations between each consecutive R-R interval (Tarvainen & Niskanen, 2012:14). The standard deviations represent the following non-linear components, namely the standard deviation 1 (SD1), which is used to measure short-term cardiac variability, and, the standard deviation 2 (SD2), which is used to measure long-term cardiac variability (Makivic *et al.* 2013:107). Standard deviation 1 (SD1) represents fast beat-to-beat variability of R-R intervals and PNS activity, whereas SD2 represents a longer-term variability in R-R intervals and both SNS and PNS activity (Makivic *et al.* 2013:107; Tulppo, 1996:245). These two parameters (SD1 = short axis and SD2 = long axis) also represents the axes of the ellipse drawn around datapoints in the Poincare plot (Tarvainen *et al.*, 2014:212). Furthermore, SD1 and SD2 can be expressed as a ratio (SD1/SD2), which is used to measure autonomic balance especially when the monitoring period is very long and there is sympathetic activation (Garrido-Esquivel *et al.*, 2011:260; Shaffer & Ginsberg, 2017:7). Therefore, researchers calculate the ratio between these parameters (SD1 and SD2) to accurately assess the balance of overall ANS activity (Garrido-

Esquivel *et al.*, 2011:260; Shaffer & Ginsberg, 2017:7). Although the last-mentioned parameters are not as well-recognised as time and frequency-domain parameters because of the sensitivity of artefacts, both parameters are still being used to assess short and long-term cardiac variability (Archarya *et al.*, 2006:1046).

Consequently, the non-linear domain parameters consist of the following HRV parameters:

- The standard deviation 1 (SD1);
- The standard deviation 2 (SD2); and
- The ratio between SD1/SD2.

While time, frequency, and non-linear-domain HRV parameters are normally presented in the form of the natural logarithm (Ln) if their distributions are skewed (Plews *et al.*, 2013:775), researchers make use of the Ln transformation due to the lower CV that is obtained and the consequent reduction in the variations of HRV parameters between individuals (Al Haddad *et al.*, 2011:603). Nonetheless, this is not recommended by researchers in sport and exercise settings due to the complexity of the calculation process (Plews *et al.*, 2013:775).

The above-mentioned HRV parameters are sensitive markers of PNS, SNS as well as ANS balance, which vary on a day-to-day basis, due to environmental factors that cause acute changes in ANS activity (Makivic *et al.*, 2013:110). Since sport and exercise settings are also influenced by numerous environmental factors (Buchheit, 2014:83), these must be considered when determining and analysing HRV parameters. For example, high-pressure circumstances will automatically bring about sympathetic predominance, which may ultimately influence trends in HRV changes (D'Ascenzi, *et al.*, 2014:233; Flatt, 2019 *et al.*, 2019:619; Garrido-Esquivel *et al.*, 2011: 262; Souza *et al.* 2019:43). Researchers should measure HRV daily to identify acute changes in ANS activity (Plews *et al.*, 2017b:701). Despite the possible influence of environmental factors on HRV, all the above-mentioned HRV parameters are regarded to be valid and reliable measures of ANS; and, therefore, are commonly used by researchers to measure HRV in sport and exercise settings (Buchheit, 2014; Garrido-Esquivel *et al.*, 2011; Plews *et al.*, 2013).

Nonetheless, while HRV is regarded to be a well-established measure through which to evaluate the stress response of the body during different physical activities, HRR can also be used as a measure to evaluate the functioning of the ANS after exercise and gauge training status and sports performance (Borresen & Lambert, 2007:504; Esco *et al.*, 2010:36). Therefore, the next section will

be dedicated to the role of HRR to serve as an indicator of ANS function.

2.4 HEART RATE RECOVERY AS AN AUTONOMIC NERVOUS SYSTEM-RELATED PARAMETER

The HRR, or post-exercise HRR, reflects the coordinated interaction between parasympathetic reactivation and sympathetic withdrawal after sport and exercise participation (Bellenger *et al.*, 2016:1462). Heart rate recovery (HRR) is regarded to be a valuable non-invasive parameter to assess the cardiovascular-parasympathetic system, as it indicates the condition of the ANS after exercise (Borresen & Lambert, 2007:504; Esco *et al.*, 2010:36). Heart rate recovery (HRR) is measured by considering the absolute (bpm) or relative decrease in HR (in percentage) over a certain time after moderate-to-heavy exercise (Daanen *et al.*, 2012:257). Faster HRR values may serve as an indicator of sport performance, as athletes who display higher HRR values, are able to recovery at a faster rate between efforts during sport and exercise activities (Inchauspe *et al.*, 2020:5). It (HRR) is also widely used as an indicator of cardiovascular fitness (Djaoui *et al.*, 2017:88; Seiler *et al.*, 2007:1370). However, although both HRV and HRR measures are recognised indicators of ANS function, researchers have found no relationship between HRV and HRR, which indicates that these variables are individually linked to the ANS (Bosquet *et al.*, 2007:367). The dissociation between HRR and resting HRV have compelled several researchers to investigate HRR as an independent ANS parameter (Barak *et al.*, 2011:373; Esco *et al.*, 2010:36; Gocentas *et al.*, 2011:14). The following section explains the protocols used to measure and determine HRV and HRR in sport and exercise settings.

2.5 PROTOCOLS TO MEASURE AND DETERMINE HEART RATE VARIABILITY AND HEART RATE RECOVERY

2.5.1 Heart rate variability measurement methods

The monitoring of individuals' adaptations to exercise involves the constant observation and evaluation of cardiac ANS status (Buchheit, 2014:80). Therefore, researchers implement specific protocols to determine HRV measurements in real-life sport and exercise settings (Coelho *et al.*, 2019:9; Dong, 2016:1531; Plews *et al.*, 2013:773). These protocols allow researchers, sports scientists, and coaches to control many aspects that may influence HRV measurements to ensure that they obtain an accurate and clear picture of athletes' ANS status during and after exercise. Furthermore, these particular protocols can also be used to evaluate HR response during moderate-to-heavy-intensity exercise. In light of the importance of using specific protocols for HRV and HRR

data collection, the following section is dedicated to protocols that researchers use when evaluating HRV and HRR in sport and exercise settings.

Electrocardiography (ECG) recorders are well-established measurement devices that use accurate algorithms for detecting QRS signals (Task Force, 1996b:1046). They can be used to obtain accurate HRV values with a sampling rate of up to 250 Hz (Task Force, 1996b:1046). Over the last few years, various ambulatory ECG recorders and Holter monitors have been developed that allow researchers to obtain accurate HRV values in out-of-laboratory settings (Gamelin *et al.*, 2006:887). However, the unaffordability and complexity of these apparatuses make the measurement of HRV very difficult, especially during physical exercise and sport participation (Gamelin *et al.*, 2006:887; Liu *et al.*, 2020:1,2). These apparatuses are more widely used in clinical studies in which participants are required to remain stationary and are not bound to time constraints (Gamelin *et al.*, 2006:887; Lopes & White, 2006:41). For this reason, wearable, wireless HR monitors were developed to allow coaches and practitioners to primarily monitor HR, and obtain accurate and time-efficient R-R intervals in sport and exercise settings (Gamelin *et al.*, 2006:887; Giles *et al.*, 2016:564).

Polar heart rate monitors are well-established, affordable measuring devices for obtaining HRV measurements in exercise and sport-related settings. (Gamelin *et al.*, 2006:887; Giles *et al.*, 2016:564). They produce consistent R-R interval recordings, which are practical and easy to use (Gamelin *et al.*, 2006:887; Giles *et al.*, 2016:568). While HR monitors are developed with the consumer in mind and not specifically for clinical or research settings (Giles *et al.*, 2016:564), the validity of Polar HR monitors (in particular) in measuring HRV has been verified. For example, researchers indicated that time (mean R-R, SDNN, RMSSD, and pNN50) and frequency-domain HRV measurements (VLF, LF, and HF) did not differ significantly ($p > 0.05$) between a Polar S810 HR monitor and an ambulatory Holter ECG recorder (Gamelin *et al.*, 2006:890). Furthermore, HRV-related parameters (SDNN, RMSSD, pNN50, VLF, LF, HF, LF/HF ratio, SD1, and SD2) were accurately measured by a Polar V800 HR monitor in comparison with an ECG recorder (Giles, 2016: 568). As a result, the Polar V800 HR monitor showed narrow limits of agreement, strong intra-class correlation coefficients, as well as small effect sizes for R-R intervals and HRV parameters, compared to ECG recordings (Giles, 2016: 570). The Suunto T6 smartwatch also showed accurate and consistent measures of resting HRV values compared to an ambulatory ECG system in healthy males (Weippert *et al.*, 2010: 785). Furthermore, the Apple smartwatch device was validated by using as reference the RR interval series provided by a Polar H7 (Hernando *et al.*, 2018:9).

The last-mentioned results suggest that the Polar, Suunto, and Apple HR monitors are valid measuring devices for determining the HRV parameters of participants (Gamelin *et al.*, 2006:887; Giles, 2016: 568; Hernando *et al.*, 2018:9). The improvement in HR monitors in recent years allows sport-related practitioners to obtain mean R-R interval measurements in situations where it was previously not possible with laboratory-based ECGs or ambulatory ECG devices (Mateo *et al.*, 2012:116; Morales *et al.*, 2013:144). Although HR monitors are considered more practical measuring instruments than traditional ECG equipment, researchers must still export the raw R-R interval data to a computer for software analysis and evaluation by a qualified individual (Flatt & Esco, 2013:85, 86). Figure 2.1 illustrates R-R intervals measured from successive heartbeat intervals, which can be obtained by using simple devices, such as wristwatch monitors (Vanderlei *et al.*, 2008: 854; Makivic *et al.*, 2013:10).



Figure 2.1: Example of R-R intervals (in ms) measured from successive heartbeat intervals (Makivic *et al.*, 2013:106)

The following procedures are followed when collecting and analysing HRV measurements:

- Firstly, in most cases participants are fitted with an HR transmitter belt around their chest, while ensuring it has adequate contact with the skin (Gamelin *et al.*, 2006:891). Researchers must control for confounding variables, such as posture, rest/exercise, free from medication and nutritional intake when raw R-R intervals are obtained by taking measurements in similar conditions (Nunan *et al.*, 2009:247).
- Secondly, high-definition, R-R interval measurements are exported to a computer for processing (Aubert *et al.*, 2003:913; Makivic *et al.*, 2013:105). The time between two R-R cycles is used to determine R-R intervals (Figure 2.1), and, depending on the objective, these measurements can be collected over different time-periods (Acharya *et al.*, 2006:1036; Makivic *et al.*, 2013:105).
- Thirdly, after obtaining raw R-R intervals, data sets are normalised by extracting various artefacts which may include procedures such as, arrhythmic events, ectopic beats, missing data, electromagnetic fields, or any environmental noise that could affect the results (Aubert *et al.*, 2003:893; Bricout *et al.*, 2010:113; Kaufmann *et al.*, 2011:1164). Data sets can be automatically normalised by using an HRV software package, such as the Kubios HRV software (Biosignal

Analysis and Medical Imaging Group at the Department of Applied Physics, University of Kuopio, Kuopio, Finland), which eliminate false QRS peaks and correct missing beats (Aubert *et al.*, 2003:894; Coelho *et al.*, 2019:3; Kaufmann *et al.*, 2011:1167; Tarvainen *et al.*, 2014:213). These sets can also be normalised by visually inspecting them in each participant and by eliminating all artefacts manually (Aubert *et al.*, 2003:894; Kaufmann *et al.*, 2011:1167; Tarvainen *et al.*, 2014:213). The analysis of ultra-short-term HRV in sport and exercise-related settings is considered valid and reliable (Nakamura *et al.*, 2016:551; Pereira *et al.*, 2016:157). However, the algorithms and analysis techniques for each data set are performed uniquely, which complicates the process of repeatability and comparability of HRV evaluations (Nunan *et al.*, 2010:1415). Therefore, the normalisation of data sets should also be standardised to ensure the accuracy and repeatability of HRV measurements (Nunan *et al.*, 2010:1415).

- Finally, after R-R intervals have been identified and cleaned, HRV data is converted to HRV parameters for interpretation by using an analysis program such as Kubios (Tarvainen *et al.*, 2014:214). They are then categorised into time, frequency, and non-linear-domain HRV parameters (Makivic *et al.*, 2013:110). Figure 2.2 below illustrates the procedure of measuring HRV.

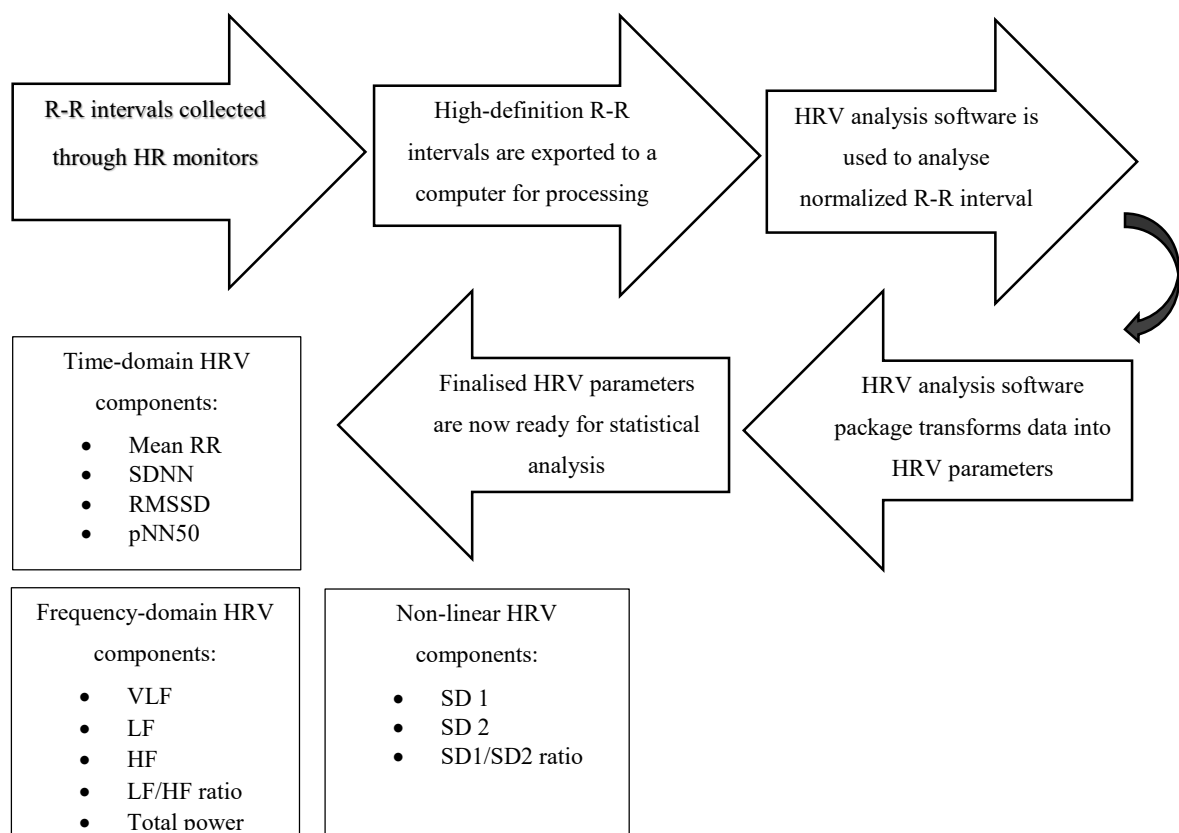


Figure 2.2: Summary of procedures for obtaining HRV parameters and values (adapted from Makivic *et al.*, 2013:106, and, Tarvainen and Niskanen, 2012:20)

2.5.1.1 Quantification of heart rate variability measurements

The past decade has seen an increase in the development of smartphone technologies and applications that allow athletes to record and easily access their HRV measurements on a mobile smartphone device (Plews *et al.*, 2017b:697; Liu *et al.*, 2020:2). Furthermore, they are able to use a wide variety of devices, such as ambulatory ECG recorders, wristwatch monitors (Polar and Suunto), and smartphone applications (BioForce, EliteHRV, and Ithlete) to obtain R-R intervals and calculate HRV measurements (Bisschoff, 2014:107; Flatt & Esco, 2013:90; Makivic *et al.*, 2013:110; Perrotta *et al.*, 2017:2296). The BioForce HRV, Ithlete HRV, and the Elite HRV smartphone applications are popular, due to their user-friendliness, affordability, and the time-effectiveness of these applications for collecting reliable HRV parameters in sport and exercises settings (Bisschoff *et al.*, 2014:22; Flatt & Esco, 2013:86,89; Perrotta *et al.*, 2017:2301). The validity and accuracy of these applications have also been investigated. For example, the HRV-related components (mean RR, SDNN, RMSSD, and peak LF) of participants that were collected using the BioForce application were significantly related ($p < 0.05$) to the values that were obtained through an Actiheart monitor (Jamieson, 2012). However, some researchers have found that the BioForce application system was only valid for assessing HRV-related parameters after recovery periods (3 minutes) following high-intensity training and not directly after high-intensity training (Bisschoff *et al.*, 2014:107). Furthermore, researchers established that the IthleteTM showed the same results as an ECG system during the evaluation of RMSSD measures in healthy adults (Flatt & Esco, 2013:90). The IthleteTM application also has the benefit of providing the time-domain HRV index, namely RMSSD, in the short time-period of under 55 seconds (Flatt & Esco, 2013:90). The Elite HRV application is a well-known smartphone application for assessing the PNS through RMSSD in sport and exercise settings (Perrotta *et al.*, 2017:2301). As a result, the RMSSD values of recreational athletes obtained by the Elite HRV smartphone application were found to be significantly correlated ($r = 0.92$ $p < 0.0001$) to those values obtained from the Kubios HRV 2.2 software (Perrotta *et al.*, 2017:2300).

However, the ability of a smartphone application to provide reliable values is just as important as its validity (Perrotta *et al.*, 2017:2301). For this reason, such applications must produce the same results in the long term, every time measurements are obtained from athletes (Perrotta *et al.*, 2017:2300). Therefore, the validity and reliability of the above-mentioned applications for analysing a variety of HRV parameters must, firstly, be scientifically proven before being used by athletes and practitioners during real-live competitions (Bisschoff *et al.*, 2014:23). In the meantime, existing studies suggest that these instruments and applications can still be used to accurately measure and interpret HRV in exercise and sport settings (Plews *et al.*, 2017a:1328).

2.5.2 Heart recovery measurement methods

Despite the value of using HRR as a simple, non-expensive tool to evaluate the cardiac autonomic function and an indicator of training status and sport performance, researchers have to consider the methodological issues that may influence HRR measurements after sport and exercise (Borresen & Lambert, 2007:510; Coelho *et al.*, 2019:8; Djaoui *et al.*, 2017:88; Esco *et al.*, 2010:37). Heart rate recovery (HRR) values can be obtained through wrist HR monitor watches, such as Polar or Suunto HR monitor watches, as it provides accurate HR measurements for coaches and athletes (Porto & Junqueira, 2009:51). These devices are especially useful for obtaining HR values and allow researchers to evaluate athletes in their competitive and training environments while remaining in a comfortable position (Gocentas *et al.*, 2011:15). Heart rate recovery (HRR) measurements can be obtained for a duration of 60 seconds, and up to 30 minutes directly after exercise, when complete exhaustion is experienced (Borresen & Lambert, 2008:642; Daanen *et al.*, 2012:257). The majority of researchers regard 60 second HRR as an accurate measure of parasympathetic reactivation, which can be used to gauge the fatigue level of athletes in sport and exercise settings (Daanen *et al.*, 2012:257; Djokic & Zagatto, 2019:346; Gocentas *et al.*, 2011:14). The methodological aspects concerning HRR measurements are more straightforward than HRV measurements. The procedures of how HRR values are obtained are explained next.

The following procedures are followed when collecting and analysing HRR measurements:

- Firstly, in most cases participants are fitted with an HR transmitter belt and wristwatch monitor, respectively placed around their chest and arm, while ensuring adequate contact with the skin.
- Secondly, maximal or submaximal exercise is done until a certain level of fatigue is reached.
- Thirdly, immediately after exercise, their HRR is recorded by an HR monitor over a certain period of time, while they stay still in a comfortable position.
- Finally, HRR values are downloaded onto a computer for analysis and then categorised into absolute (bpm) or relative (%) HRR values (Daanen *et al.*, 2012:257). The procedures of how HRR measurements are obtained are summarised in Figure 2.3 below.

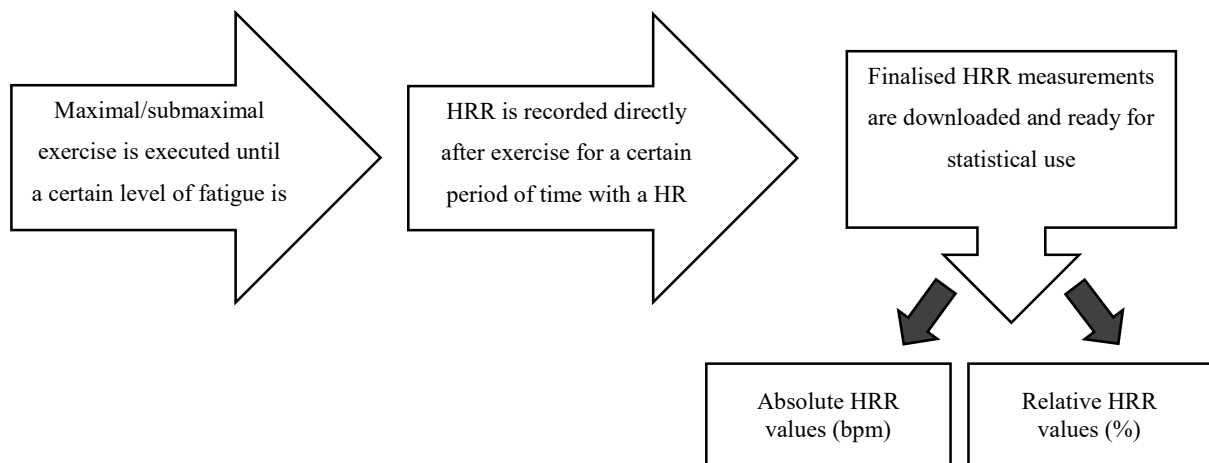


Figure 2.3: Procedures for measuring heart rate recovery (HRR) (adapted from Daanen *et al.*, 2012:257)

The above-mentioned figure (Figure 2.3) shows that HRR measurements are generally expressed in the form of absolute or relative values (Daanen *et al.*, 2012:257). The difference between exercise HR, post-exercise HR, and relative values is the total decline in the percentage of exercise HR to post-exercise HR (Daanen *et al.*, 2012:257). Heart rate recovery (HRR) can be defined as the speed at which HR decreases after a bout of exercise (Bosquet *et al.*, 2008:239). Heart rate recovery (HRR) values are usually measured when a participant reaches an HR value of above 85% of his/her theoretical maximal HR ($208 - 0.7 \times \text{age}$), after submaximal or maximal exercise (Borresen & Lambert, 2008:642; Daanen *et al.*, 2012:258; Roy & McCrory, 2015:322). Post-exercise HR is usually calculated over different time frames, normally between 30 seconds and 3 minutes after exercise (Djaoui *et al.*, 2017:88). However, the evaluation of HRR at 60 seconds after exercise is more widely used by researchers, as it is immediately available and considered more practical and time effective (Bosquet *et al.*, 2008:239; Djokic & Zagatto, 2019:346; Gocentas *et al.*, 2011:14). Heart rate recover (HRR) is also deemed to be more reliable when measured at rest than during submaximal or maximal exercise activities (Bosquet *et al.*, 2008:241). Nevertheless, the standardisation of HRR protocols is still particularly important to ensure accurate and reliable HRR measurements (Al Haddad *et al.*, 2011:603; Bosquet *et al.*, 2008:241). The last-mentioned findings show that HRV and HRR can be used to measure cardiac autonomic regulation in sport and exercise settings (Makivic *et al.*, 2013:105; Seiler *et al.*, 2007:1370). In the next section, the results of several studies that evaluated HRV in exercise and sport-related settings will be presented and discussed.

2.6 THE MEASUREMENT OF HEART RATE VARIABILITY IN EXERCISE AND SPORT SETTINGS

As mentioned before, various researchers have applied different techniques to obtain and utilise ANS-related parameters in sport and exercise settings (Flatt *et al.*, 2019:619; Makivic *et al.* 2013:105; Suetake & Kobayashi, 2017:83). Therefore, studies that have investigated the HRV of athletes during sport and exercise participation can provide researchers, sports scientist, and coaches with valuable information regarding the functional adaptations and stress responses of athletes during the last-mentioned periods (Borresen & Lambert, 2008:634; Douglas *et al.*, 2016:486; Suetake & Kobayashi, 2017:83, 84). Table 2.1 presents the findings of studies that have investigated HRV in exercise and sport settings.

Table 2.1: Summarised findings of HRV-related studies conducted in sport and exercise settings

Authors and date of publication	Number, gender, and age of participants	Purpose and methodology of the study	HRV measurements	Results and conclusions
Coelho <i>et al.</i> (2019)	11 Elite, male (age: 16.21 ± 0.62 years) and 10 female canoeists (16.01 ± 0.76 years)	This study investigated canoeists during a 10-day training camp to identify possible gender differences. The training camp included regular training without deliberate intensification to bring about functional overreaching and tapering exercise as preparation for the Olympic games.	R-R interval recordings (Ln-RMSSD _{mean} , and Ln-RMSSD _{CV}) were obtained by a portable HR device (Polar Team ² , Polar, Kempele Finland). Ln-RMSSD was calculated by the Kubios HRV Standard 3.0.0 software package (Kubios, Kuopio, Finland). HRV measurements were taken while participants maintained a comfortable, seated up-straight with open eyes, while breathing comfortably. R-R interval recordings were obtained for 2 minutes every morning, between breakfast and 30 minutes before the first training session of the day.	The within-group analysis revealed that females achieved no significant differences in Ln-RMSSD _{mean} , and Ln-RMSSD _{CV} over the training period. However, male athletes experienced a small reduction in Ln-RMSSD _{mean} during the camp. The latter also displayed higher external and internal training loads during the 10-day training camp, compared to their female counterparts. The differences between gender groups were small but translated into meaningful changes in vagally-mediated HRV results that showed a decrease in male participants during the 10-day training camp. This study found that HRV can be used to control the effects of overloading and stressors before competition periods.

R-R intervals:	Inter-beat intervals or R to R intervals
Ln-RMSSD _{mean} :	The natural logarithm of the mean square root of mean squared differences between successive R-R intervals
Ln-RMSSDCV:	The natural logarithm of the coefficient of variation of square root of mean squared differences between successive R-R intervals
HRV:	Heart rate variability

Table 2.1 (cont.): Summarised findings of HRV-related studies conducted in sport and exercise settings

Authors and date of publication	Number, gender, and age of participants	Purpose and methodology of the study	HRV measurements	Results and conclusions
Figueiredo <i>et al.</i> (2019)	16 Male, elite u/19 soccer players	This study aimed to evaluate the effects of a one-week baseline, two-week overload, followed by a one-week tapering on the (Ln-RMSSD) responses of the group and individuals before a state championship in young, elite soccer players.	HRV parameters (Ln-RMSSD _{mean} and Ln-RMSSD _{CV}) were measured every day throughout the pre-season. R-R intervals were obtained after waking up, using a Suunto Memory Belt Heart Rate Monitor (Suunto Oy, Vantaa, Finland). R-R interval recordings were analysed and transferred to a computer using the Suunto Training Manager software package. All measurements were performed for 1 minute in a quiet environment, every morning. Participants remained in a supine position while measurements were performed.	The group analysis revealed a significant time effect ($p < 0.001$) for Ln-RMSSD _{mean} during the 4-week training period. The <i>post-hoc</i> analysis indicated that Ln-RMSSD _{mean} values decreased significantly ($p < 0.008$) during the 2 weeks of overload compared to the baseline. The Ln-RMSSD _{mean} increased significantly ($p < 0.008$) during tapering phases compared to the 2 weeks of overload. This study revealed significantly higher training loads during overload periods, which resulted in significantly lower Ln-RMSSD _{mean} values. Significantly greater Ln-RMSSD _{CV} values were linked to a decrease in stress tolerance and intermittent running performance. Researchers found that when stress tolerance is measured it can be useful to improve the interpretation of HRV responses during different training periods.

R-R intervals:	Inter-beat intervals or R to R intervals
Ln-RMSSD _{mean} :	The natural logarithm of the mean square root of mean squared differences between successive R-R intervals
Ln-RMSSDCV:	The natural logarithm of the coefficient of variation of square root of mean squared differences between successive R-R intervals
HRV:	Heart rate variability

Table 2.1 (cont.): Summarised findings of HRV-related studies conducted in sport and exercise settings

Authors and date of publication	Number, gender, and age of participants	Purpose and methodology of the study	HRV measurements	Results and conclusions
Souza <i>et al.</i> (2019)	54 Males including 18 canoeists (age: 18.9 ± 1.35 years), 18 10km street runners (age: 21.12 ± 8.73 years), and 18 Jiu-jitsu athletes (age: 21.29 ± 4.50 years).	This study aimed to investigate the physiological and psychological states of athletes before competitions or training periods by measuring their HRV.	HRV measurements, such as LF/HF ratio, were obtained using a Polar RS800CX monitor (Polar Electro OY, Finland). The bands of interest were: LF (refers to sympathetic activity and includes a vagal component) and HF (refers to parasympathetic activity). The sympathovagal index (LF/HF ratio) was calculated based on standardised LF and HF values. All HRV measures were obtained for 10 minutes in a supine position.	The LF/HF ratio showed a significantly higher value ($p < 0.0001$) during the pre-competition in comparison to the pre-training periods. The results of this study revealed that both emotional and psycho-physiological indices (HRV) of stress were higher before competition periods compared to training periods, whereas differences were also shown between emotional states in the athletes of different sports. Therefore, HRV measurements can be used for determining stress responses in athletes before competition periods.

HRV:	Heart rate variability
LF:	Peak band frequency of Low Frequency component
HF:	Peak band frequency of High Frequency component
LF/HF ratio:	Ratio and partial distribution between LF and HF band powers

Table 2.1 (cont.): Summarised findings of HRV-related studies conducted in sport and exercise settings

Authors and date of publication	Number, gender, and age of participants	Purpose and methodology of the study	HRV measurements	Results and conclusions
Esco <i>et al.</i> (2016)	Nine female, collegiate soccer players (age: 21.78 ± 2.04 years).	This study aimed to investigate whether early responses in weekly measures (measured daily during week one and week three) of HRV were related to changes in $\dot{V}O_{2\max}$ values following an 11-week off-season conditioning training programme.	R-R interval recordings were collected through the Ithlete™ smartphone application with measures lasting 55 seconds. HRV values were converted to weekly Ln-RMSSD _{mean} values, which were calculated as the CV between Ln-RMSSD _{mean} and Ln-RMSSD _{CV} . Participants remained in a supine position while R-R interval recordings were taken each morning after waking up.	The Ln-RMSSD _{CV} values differed significantly between the first and third week ($r = 0.90$, $p = 0.002$) with a difference measured in $\dot{V}O_{2\max}$. The results of this study showed that the change in weekly (week one to three) Ln-RMSSD _{mean} values during an off-season conditioning programme were strongly associated with the final adaptation in $\dot{V}O_{2\max}$.

R-R intervals:	Inter-beat intervals or R to R intervals
Ln-RMSSD _{mean} :	The natural logarithm of the mean square root of mean squared differences between successive R-R intervals
Ln-RMSSDCV:	The natural logarithm of the coefficient of variation of square root of mean squared differences between successive R-R intervals
HRV:	Heart rate variability
VO ₂ max:	Maximal oxygen uptake
CV:	Coefficient of variation

Table 2.1 (cont.): Summarised findings of HRV-related studies conducted in sport and exercise settings

Authors and date of publication	Number, gender, and age of participants	Purpose and methodology of the study	HRV measurements	Results and conclusions
Nakamura <i>et al.</i> (2016)	40 Male, elite rugby players (age: 25.4 ± 5.0 years).	This study investigated the intra and inter-day reliability of ultra-short-term HRV (Ln-RMSSD) values in elite rugby union players. The Ln-RMSSD values were measured on four consecutive days during a one-week training camp.	R-R intervals were obtained by a Polar RS800CX HR monitor. HRV measures (Ln-RMSSD) were taken while participants remained in a seated position for 120 seconds.	The intra-day (ICC = 0.96, CV = 3.99%) and inter-day coefficient values (ICC = 0.90, CV = 7.65%) both indicated high and reliable measures. Therefore, ultra-short-term HRV parameters, such as Ln-RMSSD, are regarded as highly consistent measurements for evaluating elite rugby players in intra- and inter-day environments. Also, findings showed that ultra-short-term HRV measurements can be obtained and used in practical, time-restricted field conditions.

R-R intervals:	Inter-beat intervals or R to R intervals
Ln-RMSSDmean:	The natural logarithm of the mean square root of mean squared differences between successive R-R intervals
Ln-RMSSDCV:	The natural logarithm of the coefficient of variation of square root of mean squared differences between successive R-R intervals
HRV	Heart rate variability

Table 2.1 (cont.): Summarised findings of HRV-related studies conducted in sport and exercise settings

Authors and date of publication	Number, gender, and age of participants	Purpose and methodology of the study	HRV measurements	Results and conclusions
Flatt and Esco (2014)	One experienced male collegiate cross-country runner (age: 19 years).	This study aimed to investigate the relationships between resting HR, HRV measures, and aerobic performance (8-kilometre race times) in a cross-country runner throughout a competitive season of eight weeks.	R-R interval recordings were collected using the Ithlete™ smartphone application with measures lasting 55 seconds. The participant remained in a seated position when measurements were taken every morning after waking up. The HRV was converted to weekly Ln-RMSSD _{mean} values and were calculated as the CV between Ln-RMSSD _{mean} and Ln-RMSSD _{cv} . Resting HR values were obtained daily while remaining in a seated position after waking up.	A strong significant relationship ($r = 0.92$) was observed between running performance and Ln-RMSSD _{cv} . Additionally, a moderate significant relationship ($r = -0.60$) was observed between running performance and Ln-RMSSD _{mean} . The variation of weekly Ln-RMSSD _{mean} values better reflected running performance compared to weekly Ln-RMSSD _{mean} values. Therefore, this study concluded that HRV is a promising method for measuring endurance performance.

R-R intervals:	Inter-beat intervals or R to R intervals
Ln-RMSSD _{mean} :	The natural logarithm of the mean square root of mean squared differences between successive R-R intervals
Ln-RMSSDCV:	The natural logarithm of the coefficient of variation of square root of mean squared differences between successive R-R intervals
HRV:	Heart rate variability
CV:	Coefficient of variation

Table 2.1 (cont.): Summarised findings of HRV-related studies conducted in sport and exercise settings

Authors and date of publication	Number, gender, and age of participants	Purpose and methodology of the study	HRV measurements	Results and conclusions
Buchheit <i>et al.</i> (2010)	14 Male, recreationally-trained runners (age: 36 ± 7 years).	The purpose of this study was to evaluate the relationships between running performance and parasympathetic activity, both at rest and following exercise. It also assessed changes in HRV parameters throughout an eight-week training programme. Each participant executed a maximal aerobic speed and a 10-kilometre running performance test before and after the intervention.	R-R interval recordings were measured via Polar S810i HR monitors. Ln-RMSSD was obtained during a 5-minute time-period at rest, while participants breathed normally.	The Ln-RMSSD values correlated significantly with maximal aerobic speed ($r = 0.57$, $p < 0.05$) and 10-kilometre running performance ($r = 0.71$, $p < 0.01$). Study results revealed an interrelationship between ANS functioning and endurance running performance. Therefore, the study concluded that resting and post-exercise HRV values can be used to predict changes in aerobic running performance.

HR:	Heart rate
HRV:	Heart rate variability
R-R intervals:	Inter-beat intervals or R to R intervals
Ln-RMSSD:	The natural logarithm of the square root of mean squared differences between successive R-R intervals

Table 2.1 (cont.): Summarised findings of HRV-related studies conducted in sport and exercise settings

Authors and date of publication	Number, gender, and age of participants	Purpose and methodology of the study	HRV measurements	Results and conclusions
Kiviniemi <i>et al.</i> (2007)	26 Male, recreational runners were divided into a predefined training group (eight, age: 32.2 $\pm$ 5 years), an HRV guided group (nine, age: 31 $\pm$ 6 years), and a control training group (nine, age: 35 $\pm$ 8 years).	This study aimed to evaluate HRV in daily endurance exercise prescriptions. The predefined training group (n = 8) trained according to a set training programme for six days a week; the HRV guided group (n = 9) trained according to daily HRV results while the control group (n = 9) trained for four days per week. $\dot{V}O_{2peak}$ was assessed before and after four weeks of training.	R-R interval recordings were measured via Polar S810i HR monitors. HRV measurements (HF power values) were obtained every morning after waking up for 5 minutes while remaining seated and for 5 minutes while standing. In addition, pre and post-HRV were compared to baseline standards. Participants were subjected to rest or low-intensity training in cases where HRV-related parameters decreased in the HRV guided training group.	The HRV guided training group who used HRV-related parameters, such as HF power, to guide training intensity throughout training periods, revealed a significant increase (p = 0.048) in running velocity and $\dot{V}O_{2peak}$ values (p = 0.002) compared to the non-HRV guided groups. This study revealed that cardiorespiratory fitness can be monitored and enhanced by making use of HRV as a training prescription tool.

HR:	Heart rate
HRV:	Heart rate variability
R-R intervals:	Inter-beat intervals or R to R intervals
HF power:	High frequency power
$\dot{V}O_2$ peak:	Peak oxygen uptake

Table 2.1 (cont.): Summarised findings of HRV-related studies conducted in sport and exercise settings

Authors and date of publication	Number, gender, and age of participants	Purpose and methodology of the study	HRV measurements	Results and conclusions
Danieli <i>et al.</i> (2014)	20 Male, endurance-trained athletes (50 ± 7 years) and 20 male sedentary control participants (52 ± 6 years).	This study aimed to evaluate the response of endurance training on the parasympathetic activity before and after the execution of a submaximal cycling test. HRV measurements were obtained before and 30 minutes after test execution.	R-R interval recordings were measured by using a Polar RS800CX heart rate monitor and an ECG apparatus (Cardiosoft). All HRV-related parameters (SDNN, RMSSD, LF, HF, and LF/HF ratio) were measured for 5 minutes while participants breathed normally and remained in a supine position.	The HRV-related parameters (SDNN, RMSSD, and HF power) of endurance-trained athletes were significantly higher ($p < 0.05$) compared to sedentary participants. This study concluded that endurance training is associated with increased HRV after submaximal exercise

HRV:	Heart rate variability
R-R intervals:	Inter-beat intervals or R to R intervals
SDNN:	The standard deviation of R-R intervals in milliseconds
RMSSD:	The square root of mean squared differences between successive R-R intervals
LF power	Low frequency power
HF power:	High frequency power
LF/HF ratio:	Ratio and partial distribution between LF and HF band powers

Table 2.1 (cont.): Summarised findings of HRV-related studies conducted in sport and exercise settings

Authors and date of publication	Number, gender, and age of participants	Purpose and methodology of the study	HRV measurements	Results and conclusions
Buchheit <i>et al.</i> (2013)	18 Professional, male, Australian Rules football players (age: 21.9 ± 2.0 years).	This study investigated the usefulness of selected physiological and perceptual measures in monitoring fitness, fatigue, and running performance of elite football players, during a pre-season training camp of two weeks. The HRV, muscle soreness, and training load of participants were assessed before the start of every training session. The Yo-Yo Intermittent Recovery Level 2 and high-speed running tests were used as performance measures.	A vagal-related HRV parameter (Ln-SD1) was measured daily at the start of each training session by using a Polar Team 2 system (1.4.1, Polar Electro OY, Kempele, Finland).	This study found that HRV (Ln-SD1) and muscle soreness were significantly correlated ($r = 0.53$; $p < 0.001$) during the training camp. In addition, the training load was significantly related to day-to-day variations in HRV ($p < 0.001$). The results of this study showed that HRV is negatively influenced by increased muscle soreness and training load. Therefore, factors, such as muscle soreness should be considered during the evaluation of ANS measurements.

ANS:	Autonomic nervous system
HRV:	Heart rate variability
Ln-SD1:	The natural logarithm of standard deviation 1

The results presented in Table 2.1 suggest that HRV measured over 10 days allows researchers and coaches to monitor and detect early signs of overloading and the effect of stressors that athletes experience before competition periods (Coelho *et al.*, 2019:5; Souza *et al.*, 2019:43). The above-mentioned findings revealed that both emotional and psycho-physiological indices (HRV) of stress were much higher before competition periods than training periods (Souza *et al.*, 2019:43). Therefore, HRV scores may also serve as indicators of emotional and psycho-physiological stress. This notion was further substantiated by researchers who showed that athletes and coaches can make use of HRV for evaluating stress tolerance and preventing training overload before competition participation (Figueiredo *et al.*, 2019:1228). Furthermore, the above-mentioned findings show that the weekly changes in the HRV of team-sport participants during an off-season conditioning programme are strongly associated with adaptations in $\dot{V}O_{2\max}$ (Esco *et al.*, 2016:439). Researchers also regard RMSSD to be a highly consistent measurement when assessing athletes in contact sports (Nakamura *et al.*, 2016:550). However, researchers found that ultra-short-term HRV can be evaluated in real-life sport environments, especially when time is limited (Nakamura *et al.*, 2016:551). In addition, significant relationships were found between HRV, 10 kilometres running, and maximal aerobic speed performance (Buchheit *et al.*, 2010:1161).

Heart rate variability (HRV) can also be used as a tool for improving cardiorespiratory fitness and setting optimal training loads for athletes (Kiviniemi *et al.*, 2007:749; Buchheit *et al.*, 2013:554). Researchers revealed that HRV can be measured on a single day, which makes it versatile and practical for evaluating ANS status. Moreover, aerobic fitness is significantly ($p < 0.05$) associated with HRV values in endurance-trained athletes (Danieli *et al.*, 2014:56). Furthermore, practitioners found that the variation of weekly $\ln\text{-RMSSD}_{\text{mean}}$ values reflected a better running performance in comparison with weekly $\ln\text{-RMSSD}_{\text{mean}}$ values (Flatt & Esco, 2014:44). Therefore, HRV is a promising method for assessing aerobic performance during competition participation. Lastly, the time and frequency-domain parameters (SDNN and HF power) of recreational and endurance-trained athletes are regarded to be effective measures of ANS in sport and exercise settings (Danieli *et al.*, 2014:56; Kiviniemi *et al.*, 2007:749). Ultimately, practitioners, athletes, and coaches would benefit from using HRV to evaluate and establish the functional adaptations that athletes experience during exercise and competition participation. The next section will be dedicated to studies that investigated HRR in exercise and sport settings.

2.7 THE MEASUREMENT OF HEART RATE RECOVERY IN EXERCISE AND SPORT SETTINGS

Heart rate recovery (HRR) is regarded to be a valuable non-invasive technique to evaluate the cardiovascular-parasympathetic system and condition of the ANS after exercise or sport participation (Borresen & Lambert, 2007:504; Esco *et al.*, 2010:36). Table 2.2 presents the findings of studies that have investigated HRR in sport and exercise settings.

Table 2.2: Summarised findings of HRR-related studies conducted in sport and exercise settings

Authors and date of publication	Number, gender, and age of participants	Purpose and methodology of the study	HRR measurements	Results and conclusions
Bisschoff <i>et al.</i> (2018)	22 Elite, male, African badminton players (age: 23.3 ± 3.9 years)	The main purpose of this study was to determine whether HRV and HRR are related to different subjective indicators of recovery status (muscle soreness, hydration status, sleep quality and quantity, and pre-competition mood states) during four different periods: pre-match, in-match, post-match, and during in-match rest.	HRR values were taken and calculated by determining absolute values and the percentage decline in HR at 60 seconds after sets or matches stopped.	The study revealed a strong significant canonical correlation ($r = 0.96$, $p < 0.01$) between HRR, HRV, and subjective indicators of recovery status for the in-match periods. This study concluded that subjective indicators of recovery influence HRR values during badminton competition participation and should, therefore, be considered.

HRR:	Heart rate recovery
HRV:	Heart rate variability

Table 2.2 (cont.): Summarised findings of HRR-related studies conducted in sport and exercise settings

Authors and date of publication	Number, gender, and age of participants	Purpose and methodology of the study	HRR measurements	Results and conclusions
Boullosa <i>et al.</i> (2013)	Eight elite, male soccer players (age: 24.0 ± 4.0)	This study investigated the changes in ANS and fitness in elite soccer players. Players participated in small-sided, sport-specific soccer games and the Yo-Yo Intermittent Recovery Test. HRR values were obtained during the start of the pre-season and again eight weeks later during the end of the pre-season.	Ultra-short-term HRR values were obtained after small-sided games. Only after a player exceeded 85% of his predicted HR _{max} during the execution of the Yo-Yo Intermittent Recovery Test, active recovery (walking, not exceeding 4 km/h) for 20 seconds was performed. HRR values were calculated as the absolute HRR and were expressed as a percentage of VO _{max} obtained during sport-specific games.	The study revealed that the HRR of participants improved significantly ($p < 0.05$) during small-sided games from the beginning to the end of the pre-season. Greater parasympathetic reactivation occurred during the active recovery periods. Therefore, the study concluded that ultra-short-term HRR can be used to evaluate autonomic adaptations in elite soccer players.

HRR:	Heart rate recovery
VO2 max:	Maximal oxygen uptake
HRmax:	Maximal heart rate
Km/h:	Kilometre per hour

Table 2.2 (cont.): Summarised findings of HRR-related studies conducted in sport and exercise settings

Authors and date of publication	Number, gender, and age of participants	Purpose and methodology of the study	HRR measurements	Results and conclusions
Henríquez <i>et al.</i> (2013)	Ten highly trained (HT) (age: 22.0 ± 1.2 years) and eight moderately trained male wrestlers (MT) (age: 22.3 ± 0.82 years)	This study aimed to determine differences in vagal reactivation using HRR and post-exercise HRV in jiu-jitsu wrestlers. Participants took part in a maximal incremental exercise test. The HRR measurements of highly (HT) and moderately trained wrestlers (MT) were also compared.	HRR measurements were obtained for 60 seconds directly after a treadmill exercise test was performed. HRR was calculated as the absolute difference between post-exercise HR and the HR at 60 seconds after a passive recovery period.	HT wrestlers showed a significantly faster HRR ($p < 0.05$) compared to the MT wrestlers. Results indicated that 60 second, post-exercise HRR is associated with the training state of wrestlers.

HR:	Heart rate
HRR:	Heart rate recovery
HT:	Highly trained
MT:	Moderately trained

Table 2.2 (cont.): Summarised findings of HRR-related studies conducted in sport and exercise settings

Authors and date of publication	Number, gender, and age of participants	Purpose and methodology of the study	HRR measurements	Results and conclusions
Gocentas <i>et al.</i> (2011)	Eight male basketball players (age: 23 $\pm$ 3.12 years)	This study aimed to assess the changes in HRR and establish the efficacy of sport-specific measures in professional basketball players during a competitive season. Players performed intensive, sport-specific exercise drills (210 seconds in duration) at the end of each practice session for four consecutive practices throughout a competitive basketball season.	HRR measurements were obtained for 60 seconds directly after the completion of a sport-specific exercise drill. HRR was calculated by subtracting the HR after 60 seconds from the peak HR reached during the exercise drill.	Players regarded as most fit that played the most games during competition periods showed significantly faster ($p < 0.05$) HRR values compared to the players that were less fit and had the least playing time throughout the season. This study concluded that the quality of HRR differs between players of the same team and could be associated with the efficacy of sport-specific training and competitive playing time.

HRR:	Heart rate recovery
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Table 2.2 (cont.): Summarised findings of HRR-related studies conducted in sport and exercise settings

Authors and date of publication	Number, gender, and age of participants	Purpose and methodology of the study	HRR measurements	Results and conclusions
Buchheit <i>et al.</i> (2010)	14 Male, recreationally-trained runners (age: 36 ± 7 years)	The purpose of this study was to evaluate the relationships between running performance and parasympathetic activity at rest and following exercise throughout an eight-week training programme. Each participant performed a MAS test and a 10-kilometre running performance test, before and after the intervention.	HRR-related parameters were obtained every two weeks. The peak HR of participants was based on the HR measure achieved during the last five minutes of the MAS test. HRR was calculated as a decrease in HR over 60 seconds by employing a first-order exponential decrease curve.	HRR values revealed a significant negative relationship ($r = 0.54$, $p < 0.05$) with the 10-kilometre running performance test results. Therefore, post-exercise HRR indices can be used as an indicator of aerobic endurance performance.

HR:	Heart rate
HRR:	Heart rate recovery
MAS:	Maximal aerobic speed

Table 2.2 (cont.): Summarised findings of HRR-related studies conducted in sport and exercise settings

Authors and date of publication	Number, gender, and age of participants	Purpose and methodology of the study	HRR measurements	Results and conclusions
Lee and Mendoza (2012)	19 Endurance-trained athletes (age range: 21-40 years; 8 males and 11 females)	This study aimed to examine the relationships between HRR, overall aerobic fitness, and physical activity. Each participant engaged in a $\dot{V}O_{2\max}$ treadmill test and answered a physical activity questionnaire.	HRR was obtained for 60 seconds directly after complete exhaustion was reached during a $\dot{V}O_{2\max}$ test. HRR was determined as the absolute difference between the HR directly after exercise and the HR after 60 seconds during active recovery (low-intensity walking on the treadmill).	HRR correlated significantly with $\dot{V}O_{2\max}$ ($r = 0.51$, $p < 0.039$) and physical activity ($r = 0.67$, $p < 0.003$), respectively. Therefore, HRR can be used as a valid measure for assessing fitness and the autonomic recovery of endurance athletes.

HRR:	Heart Rate Recovery
$\dot{V}O_{2\max}$:	Maximum oxygen intake

The results in Table 2.2 show that HRR can be used to monitor and evaluate the cardiovascular-parasympathetic system and ANS control after exercise or sports participation (Buchheit *et al.*, 2010:1165; Lee & Mendoza, 2012:2765). Researchers also confirmed that the HRR values of team-sport players improved significantly as an indication of faster parasympathetic reactivation during active recovery periods, after only eight weeks of soccer-specific games (Boullosa *et al.*, 2013:403). Therefore, researchers concluded that HRR can be used as an indicator of cardiovascular fitness in athletes (Boullosa *et al.*, 2013:408). Similarly, HT wrestlers revealed significantly faster HRR values compared to MT wrestlers after the completion of a treadmill exercise test (Henríquez *et al.*, 2013:114). For this reason, HRR measured for 60 seconds can be used as an indicator of the training state of sport participants (Henríquez *et al.*, 2013:114). Similarly, basketball players who performed better during sport-specific exercise drills and played more matches during a competitive season showed significantly faster HRR after drills compared to their less-skilled teammates (Gocentas *et al.*, 2011:14). Furthermore, higher HRR values after exercise are associated with increased physical activity, and improved aerobic performance (Lee & Mendoza, 2012:2765). Several researchers also indicated that the HRR of endurance athletes can be used as an indicator of recovery (Buchheit *et al.*, 2010:1165; Lee & Mendoza, 2012:2765). Lastly, a study showed that the subjective recovery indicators of badminton players influenced their HRR values during a real-life competition (Bisschoff *et al.*, 2018: 14).

Overall findings suggest that HRR can be successfully measured during training and competition participation to estimate sport-specific performances of team and individual sports participants (Boullosa *et al.*, 2013:408; Henríquez *et al.*, 2013:114; Gocentas *et al.*, 2011:14). The HRR of athletes can also be used to monitor and determine training responses and participation levels. This is because athletes with higher aerobic fitness levels who compete at a higher level recover faster after sport-specific exercise, as indicated by their better HRR profiles (Boullosa *et al.*, 2013:408; Henríquez *et al.*, 2013:114). Lastly, the HRR of athletes can serve as a useful parameter to monitor functional adaptations and recovery statuses during training and sport participation (Bisschoff *et al.*, 2018; Boullosa *et al.*, 2013; Henríquez *et al.*, 2013).

The above-mentioned sections highlight the need to measure and monitor HRV and HRR parameters in sport and exercise settings. Despite the value of available research that investigated these ANS-related parameters in those specific settings, in most cases, researchers did not consider the possible influence of confounding variables such as short-term 24-hour diet, when interpreting results.

Therefore, the following section will be dedicated to research that has focused on the possible influence of diet on ANS regulation, and methods to analyse short-term diets.

2.8 THE INFLUENCE OF SHORT-TERM DIET ON AUTONOMIC NERVOUS SYSTEM REGULATION

The ANS plays a crucial role in regulating processes involved with eating behaviour and energy expenditure (Guarino *et al.*, 2017:1). In this regard, researchers have highlighted the importance of a balanced diet before sport and exercise participation to maintain optimal ANS control (Coelho *et al.*, 2019:8). For example, several researchers have reported that the nutritional and hydration status of an athlete can influence and change the regulation of the different branches of the ANS during sport and exercise participation (Clarke & Duncan, 2016:108; Havemann *et al.*, 2006:200; Lima-Silva *et al.*, 2010b:1137). Vitamins and minerals are also regarded to be crucial components for the optimal recovery, HR functioning, and muscle performance of athletes (Brisswalter & Louis 2014,316). Given these facts, the next section will be dedicated to studies that investigated the possible influence of short-term diets on the ANS of participants.

Six groups of researchers have investigated the possible influence of a short-term diet (containing either fat, carbohydrates, vitamins, or minerals) on the ANS functioning of athletes or active participants (Dogdus *et al.*, 2019; Havemann *et al.*, 2006; Kim *et al.*, 2012; Lima-Silva *et al.*, 2010a; Lima-Silva *et al.*, 2010b; Nagai *et al.*, 2005; Paolisso *et al.*, 2000). Last-mentioned studies evaluated the ANS functioning of participants before and during cycling exercises or during normal HRV study protocol conditions that did not contain exercise (Dogdus *et al.*, 2019; Havemann *et al.*, 2006; Kim *et al.*, 2012; Lima-Silva *et al.*, 2010a; Lima-Silva *et al.*, 2010b; Nagai *et al.*, 2005; Paolisso *et al.*, 2000). All information that is related to these studies is presented in Table 2.3.

Table 2.3: Summarised findings of studies that investigated the influence of diet on ANS functioning

Authors and date of publication	Number, gender, and age of participants	Purpose and methodology of the study	Influencing factor	Results and conclusions
Havemann <i>et al.</i> (2006)	Eight well-trained male endurance cyclists (age: 26.0 ± 3.3 years)	This study aimed to investigate the effect of a high-fat diet followed by one day CHO-loading on substrate metabolism, HRV, effort perception, muscle recruitment, and performance. Participants performed two trials (a 100-kilometre cycling time trial and a sixty-minute cycling test), after ingesting either a high-fat diet (68% of total energy from fat) or a high-CHO (68% of total energy from carbohydrates) diet for six days followed by one day of CHO-loading (90% of total energy from carbohydrates). The following resting HRV-related variables were measured and analysed: HF, LF, and LF/HF ratio.	High-fat diet followed by CHO-loading	A high-fat diet for six days followed by one day of CHO-loading by participants significantly increased ($p < 0.05$) pre-exercise, normalised LF power values compared to a high-CHO diet. This study concluded that a high-fat diet followed by one day of CHO-loading increased the sympathetic activity of participants during endurance training, which also included high-intensity sprint sets.

CHO:	Carbohydrate
HRV:	Heart rate variability
LF:	Low frequency power
HF:	High frequency power
LF/HF ratio:	Ratio and partial distribution between LF and HF band powers

Table 2.3 (cont.): Summarised findings of studies that investigated the influence of diet on ANS functioning

Authors and date of publication	Number, gender, and age of participants	Purpose and methodology of the study	Influencing factor	Results and conclusions
Lima-Silva <i>et al.</i> (2010a)	12 Physically active male participants (age, 28.5 ± 6.8 years).	This study aimed to investigate the effects of a short-term low and high-carbohydrate (CHO) diet ingested after exercise on HRV-related parameters. Participants performed a progressive incremental cycling protocol test (until exhaustion) and were then subjected to a low-CHO (10% of total energy from carbohydrates), or a high-CHO (80% of total energy from carbohydrates) diet for two days. The following time and frequency-domain parameters were measured: R-R intervals, SDNN, RMSSD, and pNN50. The LF power, HF power, and the LF/HF ratio were calculated for each 5-min segment of the exercise protocols.	Low-CHO and high-CHO diet intake	Significant decreases were found in the normalised HF power after a low-CHO diet was consumed, compared to a high-CHO diet. Normalised LF power values also increased significantly ($p < 0.05$) after ingesting a low-CHO diet. Consequently, the LF/HF ratio increased significantly ($p < 0.05$) in the low-CHO diet group. This study concluded that a lower intake of CHO altered ANS control by increasing SNS activity in cyclists.

SDNN:	The standard deviation of the R–R intervals
RMSSD:	The root mean square of successive differences
pNN50:	The relative quantity of successive intervals differing more than 50 milliseconds
LF/HF ratio:	Ratio and partial distribution between LF and HF band powers

Table 2.3 (cont.): Summarised findings of studies that investigated the influence of diet on ANS functioning

Authors and date of publication	Number, gender, and age of participants	Purpose and methodology of the study	Influencing factor	Results and conclusions
Lima-Silva <i>et al.</i> (2010b)	Six healthy male participants (age, 26.5 ± 6.7 years)	The purpose of this study was to investigate the effects of a low-carbohydrate (CHO) diet on HRV responses during moderate and very high-intensity exercise until exhaustion. Participants were subjected to a low (10% of total energy from carbohydrates) or moderate-CHO (65% of total energy from carbohydrates) diet until the test day. Participants performed a ninety-minute cycling exercise test followed by five-minute rest interval and subsequent one-minute cycling spells at 125% of $\dot{V}O_{2max}$ until exhaustion. The following HRV parameters were measured and assessed: LF power, HF power, LF/HF ratio, SD1, and SD2.	Low- and moderate-CHO intake	The SD2 was significantly higher ($p < 0.05$) at 5 minutes and exhaustion in the low-CHO diet group, compared to the moderate-CHO group. However, SD1, absolute HF, and LF scores at 5 minutes and exhaustion during a severe-intensity cycling exercise increased significantly ($p < 0.05$) when participants ingested a low-CHO diet. This study concluded that a low-CHO diet influenced HRV-related parameters during very high-intensity exercise, but not during moderate-intensity exercise, by increasing sympathetic activity.

VO2 max:	Maximum rate of oxygen consumption
LF/HF ratio:	Ratio and partial distribution between LF and HF band powers

Table 2.3 (cont.): Summarised findings of studies that investigated the influence of diet on ANS functioning

Authors and date of publication	Number, gender, and age of participants	Purpose and methodology of the study	Influencing factor	Results and conclusions
Nagai <i>et al.</i> (2005)	14 Healthy young males (age: 23.6 ± 0.5 years).	The purpose of this study was to investigate the metabolic and sympathetic responses when participants were subjected to high-fat meals. On the day of the test, participants were assessed for energy expenditure and fat oxidation measured by indirect calorimetry for three and a half hours after ingesting either a high-fat (70% of total energy from fat) or an isoenergetic low-fat meal (20% of total energy from fat). The following HRV-related parameters were measured: VLF, LF, HF, and LF/HF ratio.	High-fat diet	VLF increased significantly ($p < 0.05$) after ingesting a high-fat diet compared to the low-fat diet. This study concluded that a high-fat diet increased power VLF responses in participants, which is suggestive of sympathetic activity.

HRV:	Heart rate variability
VLF:	Very low frequency
LF:	Low frequency
HF:	High frequency
LF/HF ratio:	Ratio and partial distribution between LF and HF band powers

Table 2.3 (cont.): Summarised findings of studies that investigated the influence of diet on ANS functioning

Authors and date of publication	Number, gender, and age of participants	Purpose and methodology of the study	Influencing factor	Results and conclusions
Paolisso <i>et al.</i> (2000)	20 Healthy participants (11 males and 9 females (age: 35.3 ± 5.1 years).	This study aimed to investigate the possible changes in participants' HRV after an increase in plasma fatty acid concentration. Participants were randomly given a lipid emulsion infusion (10% of total energy from triacylglycerol) for three hours. The following measurements of HRV-related parameters were obtained: LF, HF, and LF/HF ratio. Measures of in-leg blood flow and leg circulatory resistance were also assessed.	Fatty acids	The LF components of participants were stimulated by the infusion of lipid and heparin ($p < 0.03$) at the second and the third hour ($p < 0.01$). HF components were inhibited ($p < 0.03$) at the second and third hours after lipid and heparin infusion. Consequently, the LF/HF ratio was significantly stimulated ($p < 0.03$) at the second hour and the third hour ($p < 0.01$) after the infusions. Therefore, this study concluded that elevated blood plasma fatty acid concentration stimulates ANS activity.

HRV:	Heart rate variability
LF:	Low frequency
HF:	High frequency
LF/HF ratio	Ratio and partial distribution between LF and HF band powers

Table 2.3 (cont.): Summarised findings of studies that investigated the influence of diet on ANS functioning

Authors and date of publication	Number, gender, and age of participants	Purpose and methodology of the study	Influencing factor	Results and conclusions
Dogdus <i>et al.</i> (2019)	102 Healthy participants (age: 36.04 ± 7.6 years) of which 53.9% were females	This study aimed to investigate the impact of a once-off oral vitamin D intake (300 000 IU) on cardiac autonomic dysfunction. Fifty-two healthy participants with a vitamin D deficiency and 50 healthy control participants were included in this study. The following HRV-related parameters were measured: SDNN, SDANN, RMSSD, pNN50, VLF power, LF power and HF power. HRV and vitamin D levels were measured before ingestion (of vitamin D) and again two months later after ingestion.	Vitamin D	HRV-related parameters, such as SDNN, SDANN, RMSSD, and pNN50, all improved significantly ($p < 0.01$) after the intake of vitamin D. This study concluded that participants experienced a significant increase in parasympathetic activity after vitamin D ingestion.

IU:	International units
HRV:	Heart rate variability
SDANN:	Standard deviation of the averages of NN intervals in all 5-minutes segments of the entire recording
pNN50:	Percentage of consecutive N-N intervals (normal to normal intervals) that differ by more than 50 milliseconds

Table 2.3 (cont.): Summarised findings of studies that investigated the influence of diet on ANS functioning

Authors and date of publication	Number, gender, and age of participants	Purpose and methodology of the study	Influencing factor	Results and conclusions
Kim <i>et al.</i> (2012)	116 Adult females (46.2±12.4)	This study aimed to investigate the association between serum calcium and magnesium levels, and HRV. The following HRV-related parameters were measured: mean R-R intervals, SDNN, RMSSD, LF power, HF power, and LF/HF ratio. Blood samples were collected to measure serum calcium and magnesium levels.	Calcium and magnesium	Mean R-R intervals decreased significantly with higher magnesium levels ($p = 0.026$). SDNN decreased significantly ($p = 0.03$) from the lowest to the highest tertile of calcium and magnesium ratio. Participants in the lowest calcium and magnesium ratio tertile showed significantly ($p < 0.05$) higher LF power compared to those in the middle and highest tertiles. This study concluded that a decrease in SDNN and LF values were significantly associated with higher calcium and magnesium ratios.
HRV: Heart rate variability SDNN: The standard deviation of the R-R intervals RMSSD: The root mean square of successive differences LF: Low frequency				

The above-mentioned findings (Table 2.3) showed that participants who consumed a low-carbohydrate (CHO) diet experienced significant increases in LFnu power during specific cycling protocol tests (Havemann *et al.*, 2006:197; Lima-Silva *et al.*, 2010a:544). One of the last-mentioned studies also revealed that a high-fat diet leads to significant increases in sympathetic activity during endurance cycling training and high-intensity sprints (Havemann *et al.*, 2006:197). Researchers also found that participants who ingested a high-fat diet experienced significant increases in VLF power, which suggest that elevated thermoregulation as a result of the high-fat diet, also caused an increase in sympathetic activity (Nagai *et al.*, 2005:359). Although this last-mentioned study associated VLF power with sympathetic activity, more recent studies have associated this parameter with sympathovagal balance (Usui & Nishida, 2017:2,7). Additionally, researchers have shown that the LF/HF ratio increased significantly with a low-CHO diet and increased blood plasma fatty acid concentrations (Lima-Silva *et al.*, 2010a:544; Paolisso *et al.*, 2000:726). Researchers also revealed that SD1, HF power, and LF power scores increased significantly at 5 minutes and exhaustion during a severe-intensity cycling exercise when participants were subjected to a low-CHO diet (Lima-Silva *et al.*, 2010b:1136,1137). Interestingly, researchers also confirmed that vitamins and minerals can influence the ANS function. For example, researchers established that vitamin D is one of several micronutrient components that can influence ANS activity by causing increases in the parasympathetic activity of participants (Dogdus *et al.*, 2019:5). Lastly, calcium and magnesium also caused significantly higher LF power responses, which may be an indication of increased sympathetic activity in participants (Kim *et al.*, 2012:121).

Despite proof that the short-term diet will influence ANS activity, only a limited number of researchers have focused their attention on the possible influence of diet on the ANS parameters in exercise settings (Havemann *et al.*, 2006; Lima-Silva *et al.*, 2010a; Lima-Silva *et al.*, 2010b). Furthermore, no researchers have focused on the possible influence of a short-term diet containing macro and micronutrients on the ANS of sport participants during real-life sports competitions or matches. Therefore, research in this regard is much needed, as the above-mentioned findings highlight the importance of adequate nutritional intake to cause and maintain an effective ANS response during exercise and sport participation.

In view of this, the next section will be dedicated to the different dietary assessment methods that are frequently used by researchers for obtaining and analysing short-term diets in different settings.

2.9 METHODS TO ANALYSE SHORT-TERM DIETS

In the modern world of sport and exercise nutrition, practitioners promote the use and implementation of dietary assessment methods in sport and exercise settings (Kozior *et al.*, 2020:564). However, researchers are still questioning the effectiveness of dietary assessment methods for obtaining and analysing dietary data, especially in sport and exercise settings (Kozior *et al.*, 2020:564). Various subjective dietary assessment methods can be used to collect and analyse the dietary intake of participants (Shim *et al.*, 2014:2). Consequently, the following assessment methods will be discussed: the 24-Hour Dietary Recall Questionnaire (24-hDRQ), Dietary Records (DR), Dietary History Assessments (DHA), and the Food Frequency Questionnaire (FFQ) (Shim *et al.*, 2014:2).

2.9.1 The 24-Hour Dietary Recall Questionnaire (24-hDRQ)

The 24-hDRQ is an open-ended questionnaire that gathers in-depth information regarding the different foods consumed over certain periods (Shim *et al.*, 2014:2). It normally requires 20 to 30 minutes to complete, in a structured interview setting and determines the habitual dietary intake of participants over a twenty-four-hour period to establish the amount of foods and beverages consumed (Shim *et al.*, 2014:2,3; Thompson & Subar. 2017:7). This includes foods consumed from each food group, food preparation methods, quantities of food that were ingested, as well as the frequency of food intake over the 24 hours (Shim *et al.*, 2014:2, 3). Food models (e.g., bowls, cups, and glasses) or photographs can be used to improve accuracy when identifying portion sizes (Shim *et al.*, 2014:2, 3). The 24-hDRQ can also be used to distinguish between habitual dietary and competition day intakes (Bradley *et al.*, 2015:476). This dietary assessment method is usually administered by a qualified interviewer (Shim *et al.*, 2014:2)

2.9.2 Dietary Records (DR)

The DR approach requires that participants self-record the types and amounts of foods and beverages they have consumed over one or more days (not more than seven days) (Day *et al.*, 2001:310; Cantwell *et al.*, 2006:440). The recording of foods and beverages normally takes place during the times of eating and beverage consumption to prevent overlooked readings (Thompson & Subar, 2017:5). The consumed foods and beverages can be measured by using household measures (e.g., cups, or tablespoons), or by using estimation models or pictures to identify portion sizes (Thompson & Subar, 2017:5). The information that is noted includes the names and branding of foods and beverages, the amounts of foods and beverages consumed, the preparation methods, and portion sizes (Thompson & Subar, 2017:5). Furthermore, someone other than participants can record the

consumed foods and beverages during assessments (Thompson & Subar, 2017:5). Finally, when the recording period concludes, a qualified interviewer should evaluate the data obtained from the participant and clarify all entries and correct any uncertainties of foods consumed (Cantwell *et al.*, 2006:440)

2.9.3 Dietary History Assessments (DHA)

The DHA approach includes any dietary assessment, which requires that participants report on their past diet and beverage consumption patterns (Slattery *et al.*, 2008:101; Thompson & Subar, 2017:14). These DHA not only allow investigators to collect information from participants about their usual eating patterns and frequency of intake, but also provide details about the typical methods of preparing meals (Slattery *et al.*, 2008:101). Instruments that are related to DHA are used to characterise various foods in detail by assessing both the techniques of food preparation and the number/amount of foods eaten (Thompson & Subar, 2017:14). Most DHA are structured as detailed interviews in which information is gathered about normal eating patterns and food lists of all amounts are compiled by obtaining participants' DR of the previous three days (Thompson & Subar, 2017:14).

2.9.4 The Food Frequency Questionnaire (FFQ)

The FFQ allows participants to report the usual frequency of all foods and beverages they consumed over a certain period by using a list of foods and beverages as an estimate (Rodrigo *et al.*, 2015:50). This questionnaire also includes questions on usual portion sizes (Rodrigo *et al.*, 2015:50). However, the FFQ can be complicated as it includes similar foods in a single question (e.g., beef, pork, or lamb), which can make it difficult for participants to answer how often beef is eaten compared to, for example, pork (Thompson & Subar, 2017:10). Various versions of the FFQ are being developed to fulfil different purposes and evaluate various population sizes (Cade *et al.*, 2004:6; Thompson & Subar, 2017:9). This approach normally makes use of a predefined, self-, or interviewer-administered structure.

The following table (Table 2.4) highlights the procedures, validity, reliability, and populations of the most used dietary assessment methods.

Table 2.4: Summarised findings of the most commonly used dietary assessment methods (Constructed from Castell *et al.*, 2015; Neuhouser *et al.*, 2008; Prentice *et al.*, 2011; Shim *et al.*, 2014; Thompson & Subar, 2017)

Dietary method	24-hour Dietary Recall Questionnaire	Dietary Records	Dietary History Assessments	Food Frequency Questionnaire
Procedure	A subjective measure that makes use of open-ended questions administered by a qualified interviewer (Shim <i>et al.</i> , 2014:2).	A subjective measure that makes use of open-ended questionnaires in a self-administered format (Shim <i>et al.</i> , 2014:2).	A subjective measure that makes use of open and close-ended questionnaires administered by a qualified interviewer (Shim <i>et al.</i> , 2014:2).	A subjective measure that makes use of a predefined, self, or interviewer-administered structure (Shim <i>et al.</i> , 2014:2).
Validity	Considered to be a valid dietary instrument for assessing energy and nutrient intakes (Castell <i>et al.</i> , 2015:47).	Considered to be a less valid dietary instrument, especially when more days progresses of dietary recall process (Thompson & Subar, 2017:6).	Considered to be a valid dietary instrument for estimating the normal dietary intake of participants (Murtaugh <i>et al.</i> , 2010:7; Thompson & Subar, 2017:14).	Considered to be a less valid dietary instrument, due to the underestimation of energy intakes (Thompson & Subar, 2017:11).
Reliability	Participants may report inaccurate information concerning their dietary intake due to limited knowledge and memory lapses regarding foods consumed (Thompson & Subar, 2017:8).	Incomplete recordings may increase significantly as more days of dietary intake are recorded. More research is required to determine the best approach for athletes (Thompson & Subar, 2017:6, 7).	This method is not standardised, which makes the comparison of dietary intake results across studies very difficult (Thompson & Subar, 2017:15).	Studies reported that this dietary method contains a substantial number of measuring errors, making it a less reliable method (Neuhouser <i>et al.</i> , 2008:1257; Prentice <i>et al.</i> , 2011:601).
Population	This assessment method can be used to measure the dietary intakes of a wide variety of populations, which includes athletes (Thompson & Subar, 2017:8).	This dietary approach was previously applied in a cohort study of the Women's Health Initiative sector (Thompson & Subar, 2017:7).	This assessment method is normally used for smaller sample sizes and has rarely been used in cohort studies (Thompson & Subar, 2017:15).	This method was developed to measure the dietary profiles of specific populations, such as African Americans, and Hispanic participants (Thompson & Subar, 2017:9).

The above-mentioned facts (Table 2.4) suggest that different dietary instruments are used for different situations when researchers want to obtain and evaluate dietary intakes. These instruments all serve as subjective measures for obtaining dietary information and make use of open- and/or closed-ended questionnaires. The 24-hDRQ is the one instrument that has previously been used to evaluate the dietary intakes of athletes (Carlsohn & Müller, 2014:2; Gamage & De Silva, 2014:2). Its immediacy enables participants to recall most of their dietary intake, which makes the 24-hDRQ more accurate than other measuring instruments (Thompson & Subar, 2017:8). Accordingly, researchers reported more accurate measurement properties for the 24-hDRQ compared to the FFQ for both absolute and relative energy, and protein intake (Kipnis *et al.*, 2003:20; Subar, 2003:8,9). Furthermore, the 24-hDRQ is regarded to be the least biased self-report instrument and therefore, is useful for most research purposes (Thompson & Subar, 2017:9).

The validity and reliability of all the above-mentioned dietary instruments for use in sport and exercise settings have not yet been verified, although the 24-hDRQ and the FFQ have previously been utilised (Bradley *et al.*, 2015:476; Braakhuis *et al.*, 2011:109; Capling *et al.*, 2017:17). However, while researchers recommend the combined use of various dietary methods, the 24-hDRQ is regarded as the most meticulous and comprehensive dietary approach that exists to date (Castell *et al.*, 2015:48). Nevertheless, the under and over-reporting of dietary intakes by participants may lead to miscalculations and inaccurate dietary profiles (Poslusna *et al.*, 2009:73). Misreporting by participants can lead to critical errors in the estimation of not only energy intake (EI), but also in the determination of all nutrient intakes (Poslusna *et al.*, 2009:73).

The above-mentioned findings and statements reveal that each dietary assessment method has its own unique challenges in terms of accurately obtaining and calculating dietary results in real-life sport settings. Therefore, future researchers must assess and improve these methods to ensure their reliability and validity for use in sport and exercise settings can be verified. However, a more recent investigation found that the peri-training nutrition (PTN) approach allows researchers and practitioners to effectively monitor the habitual dietary practices of athletes (Kozior *et al.*, 2020:564, 567). This particular approach considers the time-specific training environments of athletes and the dietary approaches aimed at optimising each athlete's specific energy and nutritional intakes, which are specific to his/her training and physiological adaptations (Kozior *et al.*, 2020:566). The PTN approach can be used for collecting pre, in and post-training energy and nutrient intakes, while also considering anthropometric, biochemical, and clinical factors that may influence athletes (Kozior *et al.*, 2020:566). Therefore, using it may improve the accuracy of

athletes' dietary assessments so that researchers can obtain more accurate dietary data when evaluating dietary profiles in sport and exercise settings.

2.10 CONCLUSIONS

Despite the availability of several studies that have investigated HRV and HRR in sport and exercise settings, researchers do not consider confounding variables, such as diet, when evaluating the ANS-related parameters of athletes during sports participation. It is in light of this background that the primary aims of this chapter were to: firstly, discuss the functioning of the ANS and the physiological mechanisms that underlie cardiac control through the different branches of the ANS; secondly, indicate, define and discuss the different parameters of HRV as well as the meaning of each; thirdly, indicate, define and discuss HRR as an ANS-related parameter; fourthly, discuss the protocols that are used to measure and determine HRV and HRR; fifthly, discuss studies that investigated the use of HRV and HRR in exercise and sport settings; sixthly, highlight the possible influence of a 24-hour (short-term) diet on HRV and HRR during sports participation; seventhly, discuss the protocols and questionnaires that are used to determine the short-term diet, and; finally, indicate and discuss limitations of current research that investigated the use of HRV and HRR in an exercise or sport setting as well as research exploring the influence of short-term diet on HRV and/or HRR.

This chapter opened by indicating the key role of ANS functioning during sport and exercise participation. The functions of the ANS were then discussed and explained. As mentioned above, the sport performance of an athlete is primarily dependent on ANS control. The literature further indicates that the ANS forms part of the central nervous system, which is responsible for regulating a large number of visceral bodily functions and processes. The branches that function under the ANS are the SNS and PNS. The SNS is associated with the fight-or-flight response and the PNS with the rest-and-digest response. However, both systems innervate the heart and regulate various bodily functions. While PNS reactivation is impaired during high-intensity training, SNS activation is stimulated during these conditions. Lastly, HRV and HRR are regarded to be acceptable measures of cardiac ANS function in athletes.

Heart rate variability (HRV) is measured by calculating the variation in time between consecutive beat-to-beat intervals of a period of time between each cardiac cycle. Once HRV values are acquired, these measurements are analysed through an HRV software package to obtain different derived variables such as time, frequency, and non-linear HRV components. The three categories

of HRV-derived variables are linked to the SNS and PNS branches of the ANS. The first category of parameters is the time-domain parameters, consisting of mean R-R, SDNN, RMSSD, and pNN50. The second category is the frequency-domain parameters and consists of VLF, LF, HF, LF/HF ratio, and total power components. Finally, the non-linear components include SD1, SD2, and the ratio between SD1 and SD2. All these HRV-related parameters are linked to either the SNS, or PNS, or indicate the balance between the activity of the last-mentioned branches of the ANS. The SNS-related parameters include the mean R-R and LF components. The PNS-related parameters include the RMSSD, pNN50, HF, and SD1 components. Lastly, the SDNN, LF/HF ratio, SD2, SD1/SD2 ratio, as well as the LF components, are all associated with ANS balance. The Ln-RMSSD is considered the most accurate of all HRV-related measures when calculated over shorter periods due to its stability during sport and exercise participation. The literature also shows that HRV-related parameters can be presented in their natural logarithmic (Ln) forms when distributions are skewed to reduce the variations in HRV-related parameter values. Overall, these aforementioned results indicate that the analysis of HRV allows researchers to evaluate the activation of different branches of the ANS so that the status of ANS control can be determined.

Heart rate recovery (HRR), which is expressed as the absolute (in bpm) or relative HR decrease (in percentage) after moderate-to-heavy-intensity exercise, is commonly used as an indicator of cardiovascular fitness, training status, and exercise capacity. Researchers agree that the main mechanism underlying the exponential cardio-deceleration after exercise is parasympathetic reactivation and sympathetic withdrawal. Therefore, HRR can be used as a simple and non-expensive tool to evaluate the cardiac ANS activity of participants. Post-exercise HR can be evaluated over different periods, normally between 30 seconds and 3 minutes after the cessation of submaximal or maximal exercise bouts. However, researchers also prefer to evaluate HRR 60 seconds directly after exercise since it is more practical and time-effective.

Both HRV- and HRR-related variables can be obtained by standard ambulatory ECG, Polar, Suunto, or Apple HR monitors, which provide users with instant measurements. Furthermore, the Polar, Suunto, and Apple HR monitors are valid, user-friendly, and affordable measuring devices to obtain HR measurements. Researchers also revealed that the last-mentioned HR monitors provide consistent time, and frequency-domain-related HRV parameters (mean R-R, SDNN, RMSSD, pNN50, VLF, LF, and HF). Therefore, the researchers suggest that the mentioned HR-devices could successfully be used to monitor ANS and evaluate athletes in their competitive and training environments.

Overall, studies suggest that HRV can successfully be measured on a long-term basis, which allows researchers and coaches to keep track of the overall training status and detect early signs of overloading and stressors placed on athletes, especially before competition periods. Furthermore, researchers found that ultra-short-term HRV can also be used as an effective measure for evaluating athletes in real-life sport environments in which there is limited time to obtain HRV values. Heart rate variability (HRV) can be used as a tool for improving cardiorespiratory fitness and setting optimal training loads for athletes. Weekly changes in HRV during different periods of a conditioning programme are strongly associated with $\dot{V}O_{2\max}$ adaptations in team-sport participants. Consequently, practitioners, athletes, and coaches would benefit from using HRV to estimate and indicate the functional adaptations that athletes experience during sport and exercise participation.

Furthermore, studies have indicated that HRR can be successfully monitored in sport and exercise settings. Heart rate recovery (HRR) can be used as a predictor of cardiovascular fitness. For example, HRR improved significantly in team-sport participants after a season of sport-specific exercises related to greater parasympathetic reactivation during active recovery periods. A further study also revealed that the HRR of wrestlers, when measured for 60 seconds post-exercise, can serve as an indicator of the training state. Moreover, another study confirmed that several subjective indicators of recovery can influence the HRR of athletes during competition participation. Consequently, this confirms that the HRR of athletes can be used to monitor and determine the training responses, aerobic fitness levels, functional adaptations, recovery statuses, and participation levels of athletes.

Even though several researchers have investigated HRV and HRR in sport and exercise settings, most did not consider the dietary intakes when evaluating the ANS-related parameters of participants. This is especially important as research into the influence of short-term diets on ANS control revealed that athletes who consume low-CHO and high-fat diets experience significant increases in sympathetic activation as indicated by an increase in LF power and LF/HF ratio. In addition, a low-CHO diet also led to significant increases in the SD1, HF, and LF values of participants at 5 minutes and exhaustion during a severe-intensity cycling exercise. Furthermore, researchers established that vitamins and minerals also influence ANS control. For example, vitamin D ingestion caused increases in the PNS activity of participants, whereas calcium and magnesium intake led to increases in the SNS activity of participants. Therefore, it is important to use accurate methods in such research.

In light of this, researchers make use of several different subjective dietary assessment methods to collect and analyse the dietary intakes of participants. These assessments include the 24-hDRQ, the DR, the DHA, and the FFQ. All these dietary assessments make use of open and/or closed-ended questionnaires. In fact, the 24-hDRQ has previously been used to evaluate the dietary intake of athletes and is regarded to be more accurate for obtaining dietary information than other measuring instruments. However, the validity and reliability of all the above-mentioned assessments for use in sport and exercise settings have not yet been proven. Therefore, future researchers must assess and improve these dietary methods to confirm their validity and reliability when utilised in sport and exercise settings. However, a very recent study found that the PTN approach may serve as an even more effective and accurate method by which researchers and practitioners can evaluate and monitor the habitual dietary practices of athletes.

Overall, the above-mentioned information indicates that HRV and HRR can serve as valuable indicators of ANS control in exercise and sport settings. However, there have only been a limited number of researchers who have investigated changes in HRV and HRR parameters during real-life sport competitions. Furthermore, despite proof that sympathetic and parasympathetic outflow can be influenced by dietary manipulation, researchers have (up to now) not included the dietary intakes of athletes as a confounding variable when investigating the influence of exercise and sport participation on changes in HRV and HRR parameters. Studies that investigated the influence of short-term diets on ANS control, have assessed HRV in laboratory-based settings by making use of progressive incremental cycling and time trial tests instead of real-life competitions. It is important to note that the high pressure associated with competition participation will automatically increase sympathetic predominance, which ultimately may influence trends in ANS control (D'Ascenzi, 2014:233; Flatt, 2019:619; Garrido-Esquivel *et al.*, 2011:262). Moreover, the above-mentioned studies manipulated the dietary intakes of participants instead of evaluating the influence of each participant's normal short-term diet on their ANS control. Therefore, the mentioned shortcomings of diet-related ANS studies, highlight the need for a study that provides both researchers and practitioners with accurate information on the influence of a normal short-term diet on the real-life competition HRV and HRR of participants.

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CHAPTER 3

ARTICLE 1:

RELATIONSHIPS BETWEEN 24-HOUR DIET AND PRE-, IN- AND POST-MATCH HEART RATE VARIABILITY OF BADMINTON PLAYERS

This article was submitted to the *Journal of Strength and Conditioning Research* and is currently under review.

Title: Relationships between 24-hour diet and pre-, in-, and post-match heart rate variability of badminton players

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ABSTRACT

The purpose of this study was to determine the relationships between a 24-hour diet and the pre-, in-, and post-match heart rate variability (HRV) of badminton players. Fourteen (14) HRV parameters of 22 male participants were measured before, during, and directly after 46 badminton matches using fixed Polar HR transmitter belts and monitors. A 24-hour diet recall questionnaire in an interview format was used to estimate the dietary intake of participants' normal in-competition days. Results of cluster analyses reduced diet-related variables were canonically correlated to pre-match, in-match, and post-match HRV parameters. The level of significance was set at $p \leq 0.05$. All canonical correlations for the relationships between the macro and micronutrient, and HRV parameters over the different match periods, were significant ($p = 0.0000-0.03$), except for the canonical correlation ($R_c = 0.97$, $p = 0.105$) between the 24-hour in-competition macronutrient intake and the post-match HRV-related variables of the badminton players. Overall, trans fatty acids, followed by available carbohydrates, were the macronutrients that had the biggest influence on changes in HRV parameters over the different match periods. Results also revealed that calcium, potassium, vitamin D, and boron were the micronutrients that contributed meaningfully to pre-match HRV changes. In addition, calcium was the only micronutrient to meaningfully contribute to HRV during the in-match period, whereas potassium was distinguished as the only micronutrient that influenced post-match HRV changes meaningfully. Therefore, study results highlight the importance of managing athletes' in-competition diets to ensure optimal functioning of the autonomic nervous system (ANS) during competition participation.

Key Words: short-term diet, macronutrients, micronutrients, autonomic nervous system, competition

INTRODUCTION

During the last few years, heart rate variability (HRV) has become a well-established measure for coaches and athletes to determine the stress response of the body during different physical activities and exercise settings (8,13,23). Heart rate variability (HRV) can be defined as the variation in time between consecutive beat-to-beat intervals when a certain time-period between each cardiac cycle elapses (3,4,43). Furthermore, HRV serves as an indicator of autonomic nervous system (ANS) functioning through activation of the sympathetic (SNS) and parasympathetic nervous system (PNS) (16). Therefore, it allows sport scientists, exercise physiologists, and coaches to evaluate and interpret cardiac autonomic regulation during sport and exercise participation (49). Moreover, it enables the last-mentioned populations to monitor training status and sport performance to set optimal training loads and ensure optimal recovery periods (12,16,49). However, even though the diet of an athlete can influence ANS functioning during sports participation (11), only a few researchers have focused their attention on the possible influence of diet on ANS parameters (24,33,34).

When the SNS is activated, it leads to the elevation of heart rate (HR) and stroke volume (SV), which reduces HRV during exercise (8). In contrast, the PNS leads to a decrease in HR and SV, which elevates the overall HRV during rest periods (35,53). Parasympathetic nervous system (PNS) reactivation is impaired during repeated high-intensity exercise such as sprinting, while SNS activation is stimulated (8). Higher SNS activation is associated with anaerobic energy processes and a rise in plasma metabolites (8). Researchers also observed a significant reduction in PNS activity after match play and attributed this to a strong SNS response (17). The high level of pressure that comes with competition participation brings about sympathetic predominance, which ultimately may influence the trends in HRV changes (14,18,22). For example, a soccer match led to significant increases in low-frequency power (LF) to high-frequency power (HF) ratios (LF/HF), due to a substantial decrease in PNS stimulation (7). Similarly, volleyball players experienced a significant decrease in the standard deviation of all normal-to-normal intervals (SDNN), the mean squared differences between successive R-R intervals (RMSSD), the percentage of consecutive N-N intervals that differ by more than 50 milliseconds (pNN50), and standard deviations of the variabilities of instantaneous R-R intervals (SD1) during two matches (26). On the other hand, the RMSSD showed a significant reduction after rugby sevens match play, which indicates a reduction in PNS activation (17). The reduction in PNS activity, as indicated by the decrease in RMSSD, was influenced by a strong SNS response during rugby sevens match play (17). Greater resting parasympathetic modulation benefits the peak-HR response at the onset of

exercise by allowing a fast parasympathetic withdrawal in combination with an extreme drive in sympathetic activity (17). Therefore, the PNS acts as a modulator of stress vulnerability and the reactive capacity of the ANS (17). All these results suggest that activities that lead to a strong SNS response will significantly reduce PNS activation after exercise (17,18,26).

Although the value of research that investigated the trends in HRV during different periods of match play cannot be denied, factors such as a short-term or a 24-hour diet that may influence HRV results are not considered during analyses of match-related HRV data (14,18,22). Only three studies have thus far investigated the influence of short-term diet on ANS control (24,33,34). For instance, Havemann et al. (24) observed that a high-fat diet (68% of total energy from fat) for six days, followed by one day of carbohydrate (CHO) loading (8-10g CHO/kg) caused a significant increase in the pre-exercise LF power of endurance cyclists, which is suggestive of increased sympathetic activation. Another study showed that a short-term, low-CHO diet (10% of total energy from CHO) led to significantly higher values of SD1 at exhaustion during a severe-intensity cycling exercise when compared to a high-carbohydrate diet (65% of total energy from CHO) (34). The standard deviations of continuous long-term, beat-to-beat interval variability (SD2) values were significantly higher at 5 minutes and exhaustion in the low (10% of total energy from CHO), compared to the high-carbohydrate dietary group (65% of total energy from CHO) (34). Furthermore, a short-term, low-carbohydrate diet (10% of total energy from CHO) caused significantly higher HF and LF values in cyclists at exhaustion, after completing high volume and intensity cycling bouts, compared to a high-CHO diet (80% of total energy from CHO) (33). Similar to macronutrients, studies have further shown that certain minerals and vitamins such as vitamin D, calcium, and dietary sodium can influence ANS functioning (2,54). The latter caused blood pressure and HR to rise, which led to increases in SNS activity in healthy participants (2,54). Therefore, the mentioned findings indicate that sympathetic and parasympathetic outflow can be influenced by dietary manipulation, supporting the theory that sympathetic activity during severe-intensity exercise and parasympathetic activity during rest can be influenced by a low-carbohydrate diet (33,34).

However, studies investigating the influence of short-term diet on ANS control, have evaluated HRV in laboratory-based settings through progressive incremental cycling and time trial tests instead of real-life competitions (24,33,34). The high degree of pressure associated with competition participation automatically increases sympathetic predominance, which may influence trends in ANS control (14,17,18). Furthermore, the above-mentioned studies

manipulated the diets of participants instead of evaluating the influence of their normal short-term diets on ANS control. The shortcomings of such diet-related HRV studies highlight the need for a study that provides researchers and practitioners alike with accurate information about the influence of a normal, short-term diet on the real-life competition HRV of participants. Therefore, the purpose of this study was to determine the relationships between a 24-hour diet and the pre-, in-, and post-match HRV of badminton players. Consequently, the research results should provide sport practitioners with more information regarding the type and composition of short-term diets that will have the greatest effect on ANS regulation during sports participation.

METHODS

Experimental Approach to the Problem

This study hypothesized that a 24-hour, low-CHO diet will lead to significantly higher SNS-related pre-, in-, and post-match HRV values of badminton players, in comparison to a high-CHO diet. It was also hypothesized that a 24-hour, low-CHO diet will lead to significantly lower PNS-related pre-, in-, and post-match HRV values of badminton players than a high-CHO diet. The hypothesis, which is related to micronutrient intakes, stated that a 24-hour diet intake that contains mineral- and vitamin-related components will lead to significantly higher SNS-related pre-, in-, and post-match HRV values of badminton players. The hypotheses were tested by making use of a selected group, repeated measures, observational, descriptive, and an *ex post facto* research design. Fourteen (14) HRV parameters were measured before, during, and after a total of 46 matches. Participants were fitted with a fixed Polar HR transmitter belt together with a Polar HR monitor (46) to record variations in beat-to-beat (R-R) intervals before, during, and after matches. A 24-hour diet recall questionnaire in an interview format was used to obtain information about participants' normal 24-hour in-competition diet.

Participants

Twenty-two (22) male, African, singles badminton players (age: 23.3 ± 3.9 years; height: 177.1 ± 3.0 cm; mass: 83.4 ± 14.5 kg) provided written informed consent to participate in the study. Participants were only eligible to participate in the study if they were actively involved in, and competed as, members of their respective teams and national badminton federations. The sample of 22 participants represented 10 African countries, namely Botswana, Cameroon, Congo, Egypt, Namibia, Nigeria, South Africa, Uganda, Zambia, and Zimbabwe. The participants' competitive badminton playing experience ranged between 4 and 12 years (9.5 ± 2.7 years). Participants needed to be injury-free at the time of testing and match play to be included.

The study was conducted in accordance with the ethical principles of the Declaration of Helsinki and the ethical guidelines of the National Health Research Ethics Council of South Africa. The study was approved by the Health Research Ethics Committee of the institution where the research was conducted (NWU-00199-14-A1-04). Permission was also obtained from the Badminton World Federation (BWF), the Badminton Confederation of Africa (BCA), the Botswana Badminton Association (BBA), and Badminton South Africa (BSA). The institutionally approved informed consent form that thoroughly explained the risks, benefits, and requirements of study participation to the players, was signed by each of the players. Players were under no obligation to participate in the study, and they could withdraw at any time during the study without fear of discrimination.

Procedures

A total of 22 male participants were measured before, during, and directly after 46 matches. They competed in the following championships: All-African Badminton Senior Championships, South African International Championships, Free State National Championships, u/19 South African National Championships, and the University Sport South Africa (USSA) Badminton Championships. While each player was measured twice, several players were measured three times. All championships took place over two to three days, which meant that players were monitored and measured on consecutive days. The exception was the Free State National Championships, which was only one day in length. On the first day of every tournament, informed consent was obtained from participating players. Furthermore, permission was received from their particular coaches to state that they may participate. However, the participants first had to agree to participate before they were allowed to take part. Thereafter, they completed a general information questionnaire regarding their exercising habits, injury incidence, and competing level. After all relevant documentation was completed, their stature and body mass measures were determined. Approximately 7 minutes before each match, participants were then fitted with a fixed Polar HR transmitter belt seven minutes (at the start of the match warm-up). This was done to record their HR every second before, during, and after each match. The warm-up period allowed the researchers to check the signals of HR monitors and players, and, to familiarize themselves with the equipment and HR transmitter belts. Before each match, a video camera was stationed on a tripod that was positioned behind each of the courts used for matches.

The research team used the 24-hour diet recall questionnaire to interview each player individually during the tournament. A digital mp3 recorder (Olympus VN-5500) was used to record every interview so that the relevant information about the diet preferences of each player could be captured. Food models, food picture books, and household measures were used to establish portion sizes. A summary of the test procedures for all competition days is presented in Table 1.

Table 1: Summary of competition day procedures.

One day prior to the first match	7 Minutes prior to match play	60 Seconds prior to match warm-up	During match play	60 Seconds after match play	24-hour recall questionnaire interviews
- Consent forms - General information questionnaire	HR monitors fitted to players	Pre-match HRV	In-match HRV	Post-match HRV	On a competition day at a time that suited players the best

* HR = Heart rate

Demographic and General Information Questionnaire. A questionnaire was used to collect the demographic and personal information of all participants. It obtained information on the age, exercise habits, injury history, competing levels, and highest achievements of each. Moreover, each subject was also expected to indicate whether they were taking any form of medication before or during the tournament.

Anthropometric measurements. Body mass was recorded to the nearest 0.1 kg, using a calibrated BFW 300 Platform scale (Adam equipment Co. Ltd., U.K.) and body stature to the nearest 0.1 cm, using a Harpenden portable stadiometer (Holtain Ltd., U.K.). The latter were used to describe the specific cohort of participants.

Video match recordings. Before the start of each match, a video camera (Sony HDR-PJ790VE Handycam, Sony Corporation, Tokyo, Japan) was stationed on a tripod behind each of the courts where matches were to be played. Video recordings of each match were downloaded onto a laptop.

The video footage was used to determine the length of each match so that researchers were able to set the correct duration for HR analyses.

Heart rate monitoring. The HR of each player was recorded using a fixed Polar HR transmitter belt at 1 second intervals throughout every match.

Heart rate variability. A fixed Polar HR transmitter belt, together with a Polar HR monitor, was used to record variations in R-R intervals before, during, and after matches. Polar HR monitors are valid devices for measuring HR and for obtaining R-R intervals since a previous study showed that time and frequency domain HRV measurements did not differ significantly ($p > 0.05$) between a Polar HR monitor (Polar S810i) and an ambulatory Holter ECG recorder (21). The Polar HR transmitter belts were adjusted according to the chest size of each subject and tied around their chest at the level of the xiphoid process. This was done after the electrode areas were moistened by tap water. A Polar HR monitor was then clipped onto the Polar HR transmitter belt of each player before he stepped on the court to begin his pre-match warm-up routine.

The R-R-intervals were obtained for the following periods: The first set of HRV-related measurements was taken 60 seconds before each pre-match warm-up, which took place five minutes before the start of each match. The next set of HRV-related measurements was calculated by determining the average R-R values for each 60-second interval of playing time during the entire match (in-match). The last set of R-R intervals were taken 60 seconds directly after play had stopped (post-match). The first and third sets of HRV-related measurements were taken while players stood upright and maintained a normal breathing pattern. Measurements were made possible by synchronizing the chronological time indexes of the digital video camera, Polar HR monitor and wristwatches that were used during data collection. After data collection, researchers meticulously went through the video footage to identify and divide different periods of the match. Researchers used Kubios HRV software (Version 2.1, Biosignal Analysis and Medical Imaging Group at the Department of Applied Physics, University of Kuopio, Kuopio, Finland) to derive the final HRV analyses from the series of R-R-intervals. The R-R data sets were exported from the Polar HR monitors via the Polar Team software package. During this process, the “error correct” function was selected which automatically filters out any erroneous values before being exported as a raw R-R data set (46). Subsequently, the “error-corrected R-R data sets” were imported to the Kubios HRV software and the built-in artifact removal option was selected during the final HRV analysis (52). This popular software has been used in several studies that have

employed HRV analysis software (40,42). Results of the following 14 HRV indices were obtained by the above-mentioned software and used in subsequent statistical analyses.

Time domain-related HRV indices consisting of:

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

Frequency domain-related HRV indices consisting of:

- Very low band peak frequencies in hertz (Peak VLF Hz);
- Low band peak frequencies in hertz (Peak LF Hz);
- High band peak frequencies in hertz (Peak HF Hz);
- The natural logarithmic transformation of LF relative power expressed as normalized units (Ln-LFnu);
- The natural logarithmic transformation of HF relative power expressed as normalized units (Ln-Hfnu);
- VLF relative power expressed as a percentage (VLF%);
- LF relative power expressed as a percentage (LF%);
- HF relative power expressed as a percentage (HF%); and
- The ratio between Ln-LFnu and Ln-HFnu components (Ln-LFnu/Ln-HFnu ratio).

Non-linear domain-related HRV indices consisting of:

- The natural logarithmic transformation of standard deviation 1 (Ln-SD1); and
- Standard deviation 2 (Ln-SD2).

A 24-hour in-competition diet. A 24-hour diet can be defined as the precise amount of food and beverages consumed over 24 hours (10). A 24-hour diet recall questionnaire was used to conduct interviews with players to estimate the dietary intake of the participants' normal in-competition day. This included the food eaten from each food group, food preparation, and quantities of food eaten at any time, as well as the frequency of food eaten over the previous 24 hours. Therefore, each subject was required to recall all their food and beverage consumptions during the previous day. Thirty-minute interviews were conducted on the competition day at a time that suited each

player. Interviews were conducted by a qualified sport scientist, who had been trained by a qualified dietician to obtain dietary data. Interviews were structured with specific probes to help participants remember all the foods they consumed throughout the relevant 24 hours. Plastic food models and picture books, as well as household measures, were used to improve accuracy when identifying portion sizes. Every interview was recorded using a digital voice recorder so that the interviewer could revert to the recording if any records were unclear.

All recorded food items were manually coded in Excel® by the researchers. This was done by using the Food Composition and Quantity manuals (South African Medical Research Council, 2019). Food recalled in household measures was converted to grams. Data accuracy was ensured by identifying outliers (very high or very low amounts) and then verifying the different values through rechecking of the original documentation and audio recordings. Spot checks were also performed on the codes to ensure that data was coded correctly. Once the data was deemed accurate, it was transferred by manually entering the food codes and weights into FoodFinder for Windows – software developed by the South African Medical Research Council (SAMRC) (32,56). FoodFinder was used to calculate the energy and nutrient intake of participants. Once the data was analyzed by using this particular software package it was exported into an Excel® sheet where it was again checked for any inaccuracies. In addition, the collected data was verified against the originally captured data to ensure that food quantities were captured correctly and also accurately reflected the energy intake and the types of food consumed over the 24 hours. The total energy intake and energy intake per meal (breakfast, lunch, dinner, and in-between-meals, or snacks) were calculated. The number of macronutrients (carbohydrate, protein, and fat) consumed were also calculated as a percentage of the total energy intake.

Several researchers have previously made use of the 24-hour diet recall questionnaire to conduct competition-day diet assessments of sport participants (9,20). Various researchers agree that the immediacy of the recall period enables participants to recall most of their dietary intake, which makes the 24-hour recall more accurate than other measuring instruments (53). In this regard, researchers reported better measurement properties for the 24-hour dietary recall compared to food frequency questionnaires for both absolute and relative energy and protein intake (29,51). Depending on the information required, the 24-hour diet recall questionnaire is regarded to be the least biased self-report instrument, and, thus, is useful for most research purposes (53).

Statistical analysis

The Statistical Data Processing package (52) was used to process the data. Firstly, a log transformation was applied to certain HRV variables to improve data normality. Secondly, descriptive statistics of each variable (minimum and maximum values, averages, and standard deviations) were calculated. Next, tree clustering, single-linkage cluster analyses, using a similarity measure $1-r$ (55) of all diet- and HRV-related variables were performed to detect clusters of measures that are related to each other. The linkage distance for the detection of different clusters was set at 0.2. The cluster analyses reduced variables were entered into canonical correlation analyses (48). The results of several diet-related variables (the first set of variables) were canonically correlated to pre-match, in-match, and post-match HRV (second set of variables), respectively. The level of significance for all analyses was set at $p \leq 0.05$. As part of the canonical correlation analyses, canonical loadings were also calculated since these values are preferred because of the deficiencies inherent to canonical weights (31). Canonical loadings are not affected by multicollinearity because the loading of each variable onto its canonical dimension is calculated in the presence of all other contributing variables to the same canonical dimension (31). The canonical loadings allow researchers to assess the relative contribution of each variable to each canonical function. Only loadings that were greater than or equal to 0.30 contributed meaningfully to the multivariate relationship and were accepted (55).

Results

The descriptive statistics of badminton players' in-match HR and HRV parameter values over different match periods are presented in Table 2.

Table 1: Descriptive statistics of badminton players' HR and HRV values over different match periods.

HRV and HR-related variables	Pre-match	In-match	Post-match
HRV - related variables			
Mean R-R (ms ⁻¹)	420.2 ± 46.2	350.9 ± 69.7	341.9 ± 38.9
Ln-SDNN (ms ⁻¹)	3.83 ± 1.2	3.45 ± 0.8	3.29 ± 1.27
Ln-RMSSD (ms ⁻¹)	3.79 ± 1.7	2.92 ± 0.98	2.38 ± 1.71
Peak VLF (Hz)	0.02 ± 0.01	0.03 ± 0.01	0.02 ± 0.01
Peak LF (Hz)	0.08 ± 0.04	0.06 ± 0.01	0.05 ± 0.03
Peak HF (Hz)	0.31 ± 0.09	0.28 ± 0.03	0.24 ± 0.07
Power VLF (%)	22.61 ± 21.6	38.71 ± 12.97	63.05 ± 30.8
Power LF (%)	27.66 ± 20.4	25.63 ± 5.5	19.71 ± 15.3
Power HF (%)	49.10 ± 35.6	35.24 ± 14.5	16.98 ± 25.3
Power Ln-LF (ms ⁻¹)	5.20 ± 2.49	4.16 ± 1.89	2.82 ± 1.44
Power Ln-HF (ms ⁻¹)	5.65 ± 4.02	5.20 ± 1.52	2.13 ± 2.33
Power Ln-LFnu	3.34 ± 1.05	3.91 ± 0.3	2.05 ± 1.44
Power Ln-HFnu	3.70 ± 0.9	3.84 ± 0.3	4.18 ± 0.54
Ln-LFnu/Ln-HFnu ratio	1.05 ± 0.6	0.95 ± 0.3	0.54 ± 0.46
Ln-SD1	3.59 ± 1.7	3.33 ± 0.9	2.21 ± 1.82
Ln-SD2	3.80 ± 1.1	3.50 ± 0.7	3.44 ± 1.09
HR-related variables			
Match HR minimum (bpm)	116.43 ± 28.29		
Match HR mean (bpm)	172.19 ± 11.25		
Match HR maximum (bpm)	197.14 ± 8.72		

* All values are mean ± SD; Mean R-R (ms⁻¹) = the mean of R-R intervals in milliseconds; Ln-SDNN (ms⁻¹) = the natural logarithmic transformation of the standard deviation of R-R intervals in milliseconds; Ln-RMSSD (ms⁻¹) = the natural logarithmic transformation of the square root of the mean squared differences between successive R-R intervals in milliseconds; Peak VLF (Hz) = very low band peak frequencies in hertz; Peak LF (Hz) = Low band peak frequencies in hertz; Peak HF (Hz) = high band peak frequencies in hertz; Power VLF (%) = VLF relative power expressed as a percentage; Power LF (%) = LF relative power expressed as a percentage; Power HF (%) = HF relative power expressed as a percentage; Power Ln-LF (ms⁻¹) = the natural logarithmic transformation of low band frequencies in milliseconds; Power Ln-HF (ms⁻¹) = the natural logarithmic transformation of high band frequencies in milliseconds; Power Ln-LFnu = the natural logarithmic transformation of LF relative power expressed as normalized units; Power Ln-HFnu = the natural logarithmic transformation of HF relative power expressed as normalized units; Ln-LFnu/LF-HFnu ratio = the ratio between the natural logarithmic transformation of the LF and HF components expressed as normalized units; Ln-SD1 = the natural logarithmic transformation of standard deviation 1; Ln-SD2 = the natural logarithmic transformation of standard deviation 2; heart rate (HR) and beats per minute (bpm).

The participants' HRV results show that the values for the majority of HRV parameters decreased from the pre-match to the in- and post-match periods. However, the following HRV parameters

show a different pattern: Peak VLF (Hz) and Power Ln-LFnu increased from the pre-match to the in-match period but then decreased again during the post-match period. The power VLF (%) and Power Ln-HFnu both increased from the pre-match period to the in- and the post-match periods. Players obtained an average HR of 172 bpm and an average maximum HR of 197 bpm during matches.

Table 3 provides the descriptive statistics of all macronutrients and vitamin-related components that were consumed by participants over 24 hours.

The tabulated results indicate that participants consumed 10 467.5 kJ of food, on average, over a 24-hour, in-competition period. Their average protein intake was 85.9g and consisted primarily of animal protein (63.9g). The participants' average total fat intake was 100.8g, of which polyunsaturated fats were the primary component (32g). Participants ingested 267.1g of CHO, on average, of which sucrose formed the main component (9.52g). Overall, protein made up 15.35% of the macronutrients that were consumed, while total fat made up 37.93%, and carbohydrates accounted for 46.73%. The amino acids that obtained the highest intake values were glutamic acid (9.24g) and aspartic acid (4.48g). An analysis of the average 24-hour vitamin intake revealed that vitamin C was most consumed (79mg), followed by oxalic acid (27.1mg), niacin (23.0mg), and vitamin E (10.6mg).

Table 3: Descriptive statistics of all macronutrient- and vitamin-related components that were consumed by participants over 24 hours.

Energy and macronutrients	Values	Vitamins	Values
Energy (kJ)	10 467.5 ± 3733.5	Vitamin A (mcg)	532.0 ± 515.4
Total protein (g)	85.9 ± 38.1	Vitamin B6 (mg)	2.10 ± 1.22
Total protein (%)	15.35 ± 4.63	Vitamin B12 (mcg)	2.05 ± 1.88
Plant protein (g)	21.5 ± 8.66	Vitamin C (mg)	79.5 ± 112.2
Animal protein (g)	63.6 ± 33.2	Vitamin D (mcg)	4.71 ± 3.45
Total fat (g)	100.8 ± 44.5	Vitamin E (mg)	10.6 ± 5.84
Total fat (%)	37.93 ± 9.00	Vitamin K (mcg)	47.6 ± 36.2
Saturated fat (g)	23.5 ± 10.4	Retinol (mcg)	124.5 ± 96.3
Mono-unsaturated fats (g)	27.1 ± 10.9	Niacin (mg)	23.0 ± 10.9
Polyunsaturated fats (g)	32.0 ± 23.4	Pantothenate (mg)	1.90 ± 1.79
Total trans-fatty acids (g)	1.38 ± 2.01	Biotin (mcg)	26.8 ± 8.39
Cholesterol (mg)	443.0 ± 185.3	A-Tocopherol (mg)	4.95 ± 3.60
Available carbohydrates (g)	267.1 ± 116.9	Folate (mcg)	270.7 ± 95.5
Available carbohydrates (%)	46.73 ± 10.70	Total carotenoids (mcg)	1086.2 ± 2357.6
Starch (g)	57.6 ± 61.2	Cryptoxanthin (mcg)	24.2 ± 26.2
Glucose (g)	2.86 ± 3.35	B-Carotene (mcg)	909.9 ± 1950.9
Fructose (g)	5.24 ± 6.88	A-Carotene (mcg)	298.9 ± 755.6
Sucrose (g)	9.52 ± 9.55	Oxalic acid (mg)	27.1 ± 39.9
Lactose (g)	2.10 ± 3.74	Lutein (mcg)	104.8 ± 98.2
Total sugars (g)	22.9 ± 21.3	Lycopene (mcg)	432.5 ± 508.0
Added sugar (g)	58.7 ± 31.8		
Leucine (g)	2.62 ± 2.77		
Lysine (g)	2.48 ± 2.54		
Arginine (g)	2.19 ± 1.75		
Alanine (g)	1.86 ± 1.71		
Aspartic acid (g)	4.48 ± 3.36		
Glutamic acid (g)	9.24 ± 5.64		

* All values are mean ± SD; kJ = kilojoules; g = grams; mg = milligrams; mcg = micrograms.

Table 4 indicates all the micronutrient, mineral-related components consumed by participants over 24 hours.

Table 4: Descriptive statistics of all micronutrient, mineral-related components that were consumed by participants over 24 hours.

Minerals	Values
Calcium (mg)	379.8 ± 228.9
Iron (mg)	9.0 ± 3.51
Magnesium (mg)	255.9 ± 108.6
Phosphorus (mg)	1271.4 ± 515.6
Potassium (mg)	2723.6 ± 1404.0
Sodium (mg)	2633.4 ± 1027.6
Chlorine (mg)	1650.9 ± 855.3
Zinc (mg)	7.57 ± 4.97
Chromium (mcg)	32.3 ± 21.1
Selenium (mcg)	47.8 ± 13.4
Manganese (mcg)	1594.3 ± 863.2
Iodine (mcg)	70.0 ± 28.0
Boron (mcg)	457.3 ± 287.0
Phytate (mg)	377.9 ± 210.0
Malic acid (mg)	461.7 ± 480.0
Citric acid (mg)	491.2 ± 615.5

* All values are mean ± SD; mg = milligrams; mcg = micrograms.

Table 4 shows that potassium (2723.6mg), sodium (2633.4mg), chlorine (1650.9mg), and phosphate (1271.4mg) are the minerals that were consumed the most during the 24-hour period.

In an attempt to, firstly, identify diet-related variables associated with each other, and, to retain only the relevant variables for the canonical correlation analyses, cluster analyses were performed. The number of macronutrient variables was reduced from 24 to seven variables, which included the following variables: total protein, total trans fatty acids, cholesterol, available carbohydrates, lactose, total sugars, and added sugars. On the other hand, the micronutrient variables were reduced from 36 to the following 11 variables, namely: calcium (Ca), potassium (K), zinc (Zn), chromium (Cr), selenium (Se), iodine (I), boron (B), vitamin C, vitamin D, citric acid, and lutein.

Since the researchers only focused on the relationships between the components of a 24-hour diet (predictor variables) and the HRV (outcome variables) of participants, only the canonical correlation analyses' results that are related to this purpose, are discussed.

Pre-match

The cluster analysis reduced the pre-match HRV variables from 16 to the following 5 variables: Ln-RMSSD (ms^{-1}), Peak VLF (Hz), Peak LF (Hz), Power VLF (%), and Power Ln-LFnu. The canonical analysis reduced variables were included in the first canonical correlation analysis that aimed to determine the relationship between macronutrient and pre-match HRV-related variables. The results of the latter analysis are presented in Table 5.

Table 5. Canonical correlation analysis summary of the relationship between the macronutrient intake and the pre-match HRV-related variables of badminton players.

Number of variables	Canonical correlation (Rc): 0.93; $\text{Chi}^2(35) = 51.99$; $*p = 0.03$	
	Left set 5	Right set 7
Variance extracted	100.00%	84.06%
Total redundancy	53.14%	36.97%
Variables: 1	Ln-RMSSD (ms^{-1})	Total protein (g)
2	Peak VLF (Hz)	Total trans-fatty acids (g)
3	Peak LF (Hz)	Cholesterol (mg)
4	Power VLF (%)	Available carbohydrates (g)
5	Power Ln-LFnu	Lactose (g)
6		Total sugars (g)
7		Added sugar (g)

* = $p \leq 0.05$; Rc = canonical correlation; Ln-RMSSD (ms^{-1}) = the natural logarithmic transformation of the square root of the mean squared differences between successive R-R intervals in milliseconds; Peak VLF (Hz) = very low band peak frequencies in hertz; Peak LF (Hz) = Low band peak frequencies in hertz; Power VLF (%) = VLF relative power expressed as a percentage; Power Ln-LFnu = the natural logarithmic transformation of LF relative power expressed as normalized units; g = grams; mg = milligrams

A strong significant canonical correlation of 0.93 ($p = 0.03$) was found between macronutrient intake and the pre-match HRV-related variables of participants. Therefore, the canonical function accounted for about 80.44% ($r^2 \times 100$) of the total variation between the two canonical variants. The variance extracted values were also calculated, which indicated the average amount of variance extracted from the variables in the respective set by all canonical roots. This calculation showed that 84.06% of the variance could be extracted from the right set and a total of 100.00% from the left set of variables. The total redundancy values showed that 53.14% of the variance in the pre-match HRV-related variables could be accounted for by the macronutrient-related variables. The canonical loadings indicated that the macronutrient-related variables that

contributed the most to the relationship during the last-mentioned period were trans fatty acids (g) (0.65), available carbohydrates (g) (0.47), and total sugars (g) (0.35), while, the HRV-related variables that served as the largest contributors to the HRV score were Peak VLF (Hz) (0.88), Peak LF (Hz) (-0.59), Power VLF (%) (0.49), and Ln-RMSSD (ms^{-1}) (-0.45).

In the second canonical correlation analysis, the relationship between micronutrient and pre-match HRV-related variables was determined. The results of this analysis are displayed in Table 6.

Table 6: Canonical correlation analysis summary of the relationship between the micronutrient intake and the pre-match HRV-related variables of badminton players.

Canonical correlation (R_c): 0.98; $\text{Chi}^2(55) = 101.77$; $*p = 0.0001$		
Number of variables	Left 5	Right 11
Variance extracted	100.00%	50.23%
Total redundancy	81.89%	33.26%
Variables: 1	Ln-RMSSD (ms^{-1})	Calcium (mg)
2	Peak VLF (Hz)	Potassium (mg)
3	Peak LF (Hz)	Zinc (mg)
4	Power VLF (%)	Chromium (mcg)
5	Power Ln-LFnu	Selenium (mcg)
6		Iodine (mcg)
7		Boron (mcg)
8		Vitamin C (mg)
9		Vitamin D (mcg)
10		Citric acid (mg)
11		Lutein (mcg)

* = $p \leq 0.05$; R_c = canonical correlation; Ln-RMSSD (ms^{-1}) = the natural logarithmic transformation of the square root of the mean squared differences between successive R-R intervals in milliseconds; Peak VLF (Hz) = very low band peak frequencies in hertz; Peak LF (Hz) = Low band peak frequencies in hertz; Power VLF (%) = VLF relative power expressed as a percentage; Power Ln-LFnu = the natural logarithmic transformation of LF relative power expressed as normalized units; mg = milligrams; mcg = micrograms

A strong significant canonical correlation of 0.98 ($p = 0.0001$) was found between micronutrient and pre-match HRV-related variables of participants. The canonical function accounted for about 96.04% ($r^2 \times 100$) of the total variation between the two canonical variants. The variance extracted values showed that 100.00% and 50.23% could be extracted for the left and right sets, respectively.

The total redundancy values showed that, on average, 81.89% of the variance in the five pre-match HRV parameters could be accounted for by the 11 micronutrient-related variables. The canonical loadings showed that the micronutrient-related variables that contributed the most to the relationship during last-mentioned period were calcium (mg) (-0.51), potassium (mg) (-0.50), vitamin D (mcg) (0.45), and boron (mcg) (-0.35). Finally, the HRV-related variables that served as the largest contributors to the HRV score were Ln-RMSSD (ms^{-1}) (0.97), Power Ln-LFnu (-0.80), Power VLF (%) (-0.60), and Peak LF (Hz) (0.55).

In-match

The total of 16 in-match HRV-related variables was reduced to the following eight variables by the cluster analysis: Mean RR (ms^{-1}), Ln-RMSSD (ms^{-1}), Peak VLF (Hz), Peak LF (Hz), Peak HF (Hz), Power LF (%), Power Ln-LFnu and Ln-LFnu/Ln-HFnu ratio. The latter were included in the third canonical correlation analysis to calculate the relationship between macronutrients and in-match HRV-related variables. These results are displayed in Table 7.

The canonical correlation revealed a significant canonical correlation of 0.99 ($p = 0.01$). The canonical function, therefore, accounted for about 98.01% ($r^2 \times 100$) of the total variation between the two canonical variants. The variance extracted values showed that 86.19% and 100.00% could be extracted for the left and right set, respectively. The total redundancy values revealed that 46.82% of the variance in the eight HRV parameters could be accounted for by the seven macronutrient-related variables. The macronutrient-related variables that contributed the most to the relationship during the last-mentioned period were trans fatty acids (g) (-0.94), added sugar (g) (0.71), available CHO (g) (0.45), and total sugars (g) (0.31). Finally, the HRV-related variables that served as the largest contributors to the HRV score were Ln-RMSSD (ms^{-1}) (-0.87), Peak LF (Hz) (-0.84), Power Ln-LFnu (0.61), Peak VLF (Hz) (-0.45) and Ln-LFnu/Ln-HFnu ratio (0.41).

Table 7: Canonical correlation analysis summary of the relationship between the macronutrient intake and the in-match HRV-related variables of badminton players.

Number of variables	Canonical correlation (Rc): 0.99; Chi ² (56) = 82.51; * <i>p</i> = 0.01	
	Left 8	Right 7
Variance extracted	86.19%	100.00%
Total redundancy	46.82%	48.12%
Variables: 1	Mean RR (ms ⁻¹)	Total protein (g)
2	Ln-RMSSD (ms ⁻¹)	Total trans-fatty acids (g)
3	Peak VLF (Hz)	Cholesterol (mg)
4	Peak LF (Hz)	Available carbohydrates (g)
5	Peak HF (Hz)	Lactose (g)
6	Power LF (%)	Total sugars (g)
7	Power Ln-LFnu	Added sugar (g)
8	Ln-LFnu/Ln-HFnu ratio	

* = $p \leq 0.05$; Rc = canonical correlation; Mean R-R (ms⁻¹) = the mean of R-R intervals; Ln-RMSSD (ms⁻¹) = the natural logarithmic transformation of the square root of the mean squared differences between successive R-R intervals in milliseconds; Peak VLF (Hz) = very low band peak frequencies in hertz; Peak LF (Hz) = Low band peak frequencies in hertz; Peak HF (Hz) = high band peak frequencies in hertz; Power LF (%) = LF relative power expressed as a percentage; Power Ln-LFnu = the natural logarithmic transformation of LF relative power expressed as normalized units; Ln-LFnu/LF-HFnu ratio = the ratio between the natural logarithmic transformation of the LF and HF components expressed as normalized units; g = grams; mg = milligrams

The next canonical correlation analysis revealed the relationship between the micronutrient and the in-match HRV-related variables. The results are displayed in Table 8.

Table 8: Canonical correlation analysis summary of the relationship between the micronutrient intake and the in-match HRV-related variables of badminton players.

Canonical correlation (Rc): 0.99; Chi ² (88) = 196.24; ^{*p} = 0.000		
Number of variables	Left 8	Right 11
Variance extracted	100.00%	75.87%
Total redundancy	70.03%	44.55%
Variables:		
1	Mean RR (ms ⁻¹)	Calcium (mg)
2	Ln-RMSSD (ms ⁻¹)	Potassium (mg)
3	Peak VLF (Hz)	Zinc (mg)
4	Peak LF (Hz)	Chromium (mcg)
5	Peak HF (Hz)	Selenium (mcg)
6	Power LF (%)	Iodine (mcg)
7	Power Ln-LFnu	Boron (mcg)
8	Ln-LF/HF Nu ratio	Vitamin C (mg)
9		Vitamin D (mcg)
10		Citric acid (mg)
11		Lutein (mcg)

* = $p \leq 0.05$; Rc = canonical correlation; Mean R-R (ms⁻¹) = the mean of R-R intervals; Ln-RMSSD (ms⁻¹) = the natural logarithmic transformation of the square root of the mean squared differences between successive R-R intervals in milliseconds; Peak VLF (Hz) = very low band peak frequencies in hertz; Peak LF (Hz) = Low band peak frequencies in hertz; Peak HF (Hz) = high band peak frequencies in hertz; Power LF (%) = LF relative power expressed as a percentage; Power Ln-LFnu = the natural logarithmic transformation of LF relative power expressed as normalized units; Ln-LFnu/LF-HFnu ratio = the ratio between the natural logarithmic transformation of the LF and HF components expressed as normalized units; mg = milligrams; mcg = micrograms

The analysis revealed a strong significant canonical correlation of 0.99 ($p = 0.000$). The canonical function, therefore, accounted for about 98.01% ($r^2 \times 100$) of the total variation between the two canonical variants. The variance extracted values showed that 100.00% and 75.87% could be extracted for the left and right sets, respectively. The total redundancy values revealed that 70.03% of the variance in the eight HRV parameters could be accounted for by the 11 micronutrient-related variables. The micronutrient-related variable that contributed the most to the relationship during the last-mentioned period was calcium (mg) (-0.35). All other mineral-related variables obtained canonical loading values of under 0.30, which was not meaningful. Finally, the HRV-related variables that served as the largest contributors to the HRV score, were Peak VLF (Hz) (-0.92), Power Ln-LFnu (0.50), Ln-RMSSD (ms⁻¹) (-0.48), Peak LF (Hz) (-0.35) and Mean RR (ms⁻¹) (0.33).

Post-match

A total of 16 HRV-related variables was reduced to the following eight parameters by means of the cluster analysis: Mean RR (ms^{-1}), Ln-RMSSD (ms^{-1}), Peak VLF (Hz), Peak LF (Hz), Power Ln-LF (ms^{-1}), Power VLF (%), Power LF (%) and Power Ln-LFnu. These results are presented in Table 9.

Table 9: Canonical correlation analysis summary of the relationship between the macronutrient intake and the post-match HRV-related variables of badminton players.

	Canonical correlation (Rc): 0.97; $\text{Chi}^2(56) = 69.62$; $p = 0.105$	
Number of variables	Left 8	Right 7
Variance extracted	95.15%	100.00%
Total redundancy	51.57%	50.22%
Variables: 1	Mean RR (ms^{-1})	Total protein (g)
2	Ln-RMSSD (ms^{-1})	Total trans-fatty acids (g)
3	Peak VLF (Hz)	Cholesterol (mg)
4	Peak LF (Hz)	Available carbohydrates (g)
5	Power Ln-LF (ms^{-1})	Lactose (g)
6	Power VLF (%)	Total sugars (g)
7	Power LF (%)	Added sugar (g)
8	Power Ln-LFnu	

Rc = canonical correlation; Mean R-R (ms^{-1}) = the mean of R-R intervals in milliseconds; Ln-RMSSD (ms^{-1}) = the natural logarithmic transformation of the square root of the mean squared differences between successive R-R intervals in milliseconds; Peak VLF (Hz) = very low band peak frequencies in hertz; Peak LF (Hz) = Low band peak frequencies in hertz; Power Ln-LF (ms^{-1}) = the natural logarithmic transformation of low band frequencies in milliseconds; Power VLF (%) = VLF relative power expressed as a percentage; Power LF (%) = LF relative power expressed as a percentage; Power Ln-LFnu = the natural logarithmic transformation of LF relative power expressed as normalized units; g = grams; mg = milligrams

The canonical correlation revealed a non-significant canonical correlation of 0.97 ($p = 0.105$). The canonical function, therefore, accounted for about 94.09% ($r^2 \times 100$) of the total variation between the two canonical variants. The variance extracted values showed that 95.15% and 100.00% could be extracted for the left and right sets, respectively. The total redundancy values revealed that 51.57% of the variance in the eight HRV parameters could be accounted for by the seven macronutrient-related variables. The macronutrient-related variables that contributed the most to the relationship during the last-mentioned period were trans fatty acids (g) (-0.84), added sugar (g)

(0.66), available CHO (g) (0.52) and total sugar (g) (0.41). On the other hand, the HRV-related variables that served as the largest contributors to the HRV score, were Ln-RMSSD (ms^{-1}) (-0.92), Peak VLF (Hz) (0.73), Power Ln-LF (ms^{-1}) (-0.68), Power Ln-LFnu (-0.61) and Power LF (%) (0.36).

The next canonical correlation analysis revealed the relationship between the micronutrient and the post-match HRV-related variables. The results are displayed in Table 10.

Table 10: Canonical correlation analysis summary of the relationship between the micronutrient intake and the post-match HRV-related variables of badminton players.

Number of variables	Canonical correlation (Rc): 0.99; Chi ² (88) = 180.20; <i>*p</i> = 0.0000	
	Left 8	Right 11
Variance extracted	100.00%	68.17%
Total redundancy	75.52%	43.71%
Variables: 1	Mean RR (ms^{-1})	Calcium (mg)
2	Ln-RMSSD (ms^{-1})	Potassium (mg)
3	Peak VLF (Hz)	Zinc (mg)
4	Peak LF (Hz)	Chromium (mcg)
5	Power Ln-LF (ms^{-1})	Selenium (mcg)
6	Power VLF (%)	Iodine (mcg)
7	Power LF (%)	Baron (mcg)
8	Power Ln-LFnu	Vitamin C (mg)
9		Vitamin D (mcg)
10		Citric acid (mg)
11		Lutein (mcg)

* = $p \leq 0.05$; Rc = canonical correlation; Mean R-R (ms^{-1}) = the mean of R-R intervals in milliseconds; Ln-RMSSD (ms^{-1}) = the natural logarithmic transformation of the square root of the mean squared differences between successive R-R intervals in milliseconds; Peak VLF (Hz) = very low band peak frequencies in hertz; Peak LF (Hz) = Low band peak frequencies in hertz; Power Ln-LF (ms^{-1}) = the natural logarithmic transformation of low band frequencies in milliseconds; Power VLF % = VLF relative power expressed as a percentage; Power LF (%) = LF relative power expressed as a percentage; Power Ln-LFnu = the natural logarithmic transformation of LF relative power expressed as normalized units; mg = milligrams; mcg = micrograms

The analysis revealed a strong significant canonical correlation of 0.99 ($p = 0.000$). The canonical function, therefore, accounted for about 98.01% ($r^2 \times 100$) of the total variation between the two canonical variants. The variance extracted values showed that 100.00% and 68.17% could be

extracted for the left and right sets, respectively. The total redundancy values revealed that 75.52% of the variance in the eight HRV parameters could be accounted for by the 11 micronutrient-related variables. The micronutrient-related variable that contributed the most to the relationship during the last-mentioned period was potassium (mg) (-0.35). All other mineral-related variables obtained canonical loading values of under 0.30, which was not meaningful. Finally, the HRV-related variables that served as the largest contributors to the HRV score, were Mean RR (ms^{-1}) (0.61), Power Ln-LF (ms^{-1}) (0.61), and Power Ln-LFnu (0.39).

DISCUSSION

To the researchers' knowledge, this is the first study of its kind to investigate the effects of dietary intake on the parameters of HRV during different periods of a real-life badminton competition. Furthermore, this is the first study that extensively evaluated the 24-hour in-competition diet profiles of male badminton players from Africa. However, since the study's purpose was not to analyze and compare the dietary profiles of players with prescribed dietary guidelines, this is not something that will be further discussed.

The canonical correlation analyses for the relationships between the 24-hour macronutrient intake and the competition-related HRV parameters measured during the pre-, in- and post-match periods revealed the following canonical correlations (R_c), respectively: $R_c = 0.93$ ($p = 0.03$), $R_c = 0.99$ ($p = 0.01$) and $R_c = 0.97$ ($p = 0.105$). The canonical correlations for the relationships between the 24-hour micronutrient intake and the competition-related HRV parameters over the last-mentioned match periods were as follows: $R_c = 0.98$ ($p = 0.001$), 0.99 ($p = 0.0000$) and $R_c = 0.99$ ($p = 0.0000$). Therefore, all the canonical correlation analyses revealed strong correlations between 0.93 and 0.99, as well as canonical functions, that accounted for between 80.44% and 98.01% of the total variation between the two canonical roots. Furthermore, all correlations were significant ($p = 0.0000$ -0.03), except for the canonical correlation ($R_c = 0.97$, $p = 0.105$) between the 24-hour in-competition macronutrient intake and the post-match HRV-related variables of badminton players. Furthermore, results also showed that 53.14%, 46.82% and 51.57% of the variance in the respective pre-, in- and post-match HRV-related variables could be accounted for by the macronutrient-related variables. Finally, the percentages of the variance in the pre- (81.89%), in- (70.03%), and post-match (75.52%) HRV-related variables, could be accounted for by the micronutrient-related variables were much higher.

In an attempt to further analyze the influence of specific diet-related components in the HRV parameter trends, canonical loadings were also calculated for each match period. Canonical loadings revealed that an increase in the consumption of trans fatty acids, available CHO, and total sugars had a direct positive influence on the pre-match PNS-related parameters of Peak VLF in Hz and as a percentage. However, the consumption of the same macronutrients was negative related to the SNS-related HRV parameter of Peak LF (Hz) and Ln-RMSSD, which is a PNS-related parameter. Moreover, an increase in the consumption of calcium, potassium and boron was related to increases in Power Ln-LFnu and Power VLF (%), which are SNS- and PNS-related parameters, respectively. Lastly, the intake of vitamin D had the opposite effect on the last-mentioned variables and was positively related to changes in the PNS-related parameter of Ln-RMSSD and an SNS-related parameter of Peak LF (Hz).

The second set of canonical analyses revealed that an increase in the consumption of added sugar, available CHO, and total sugar had a direct positive influence on the in-match SNS-related parameter of Power Ln-LFnu and Ln-LFnu/Ln-HFnu ratio, which is a parameter of ANS balance. However, the consumption of the last-mentioned macronutrients was negatively related to PNS-related Ln-RMSSD (ms^{-1}) and Peak VLF (Hz), as well as the SNS-related Peak LF (Hz). Additionally, trans fatty acids had a positive effect on the last-mentioned HRV parameters but influenced Power Ln-LFnu and Ln-LFnu/Ln-HFnu ratio negatively. Furthermore, an increase in the consumption of calcium was related to increases in the PNS-related parameters of Peak VLF (Hz) and Ln-RMSSD (ms^{-1}), and the SNS-related Peak LF (Hz), whereas Power Ln-LFnu and Mean R-R (ms^{-1}) was negatively influenced by an increase in calcium consumption.

The post-match related canonical loadings revealed that an increase in the consumption of added sugar, available CHO, and total sugars had a direct positive influence on the PNS-related parameter of Peak VLF (Hz) and the SNS-related parameter of Power LF (%). However, the consumption of the same macronutrients were negatively related to the PNS-related HRV parameter of Ln-RMSSD (ms^{-1}) and the SNS-related parameters of Power Ln-LF (ms^{-1}) and Power Ln-LFnu. The consumption of trans fatty acids had the opposite effect on all the last-mentioned HRV parameters due to positive relationships between the intake of trans fatty acids and these parameters of HRV. However, Peak VLF (Hz) and Power LF (%) were negatively influenced by the last-mentioned macronutrient. At the same time, an increase in the consumption of potassium was negatively related to changes in the SNS-related parameters of Power Ln-LF (ms^{-1}) and Power Ln-LFnu as well as the parameter of ANS balance, namely Mean R-R (ms^{-1}).

Overall, the above-mentioned findings suggest that trans fatty acids were the macronutrient that had the biggest influence on changes in HRV parameters over the different match periods. This was followed by available CHO that had the second biggest influence during the three-match periods. Added sugars were identified as the third most influential macronutrient in terms of both the in-match and post-match periods, whereas total sugars served as the third most contributing macronutrient to pre-match HRV changes. The micronutrient that contributed the most to pre-and in-match HRV changes, was calcium. Potassium was distinguished as the primary micronutrient to influence post-match HRV changes.

As previously mentioned, only three studies have evaluated the influence of short-term diet on ANS control (24,33,34). Although these studies only focused on the influence of CHO and fat consumption on the HRV control of endurance cyclists and healthy males, findings suggest that lowered CHO and higher fat consumption lead to increased pre-exercise sympathetic activation and higher PNS and SNS activation at exhaustion, during a severe-intensity cycling exercise (24,33,34). Similarly, researchers found that a short-term, low-CHO diet can lead to greater cardiovascular stress, and, may perhaps impair performance indicators during exercise (33). Furthermore, two cohort studies also indicated that the intake of a great amount of trans fatty acids by young (aged 19 years) and older participants (aged 72 years) over five years led to a significant decrease in the parameters of ANS balance, namely SDNN and total power (50). On the other hand, Nagai et al. (38) observed that a high-fat diet (70% of total energy from fat) in healthy young males caused a significant increase in the PNS-related parameter of Power VLF (%), findings that are more or less similar to the results of our study which indicated that trans fatty acids had the biggest influence on the PNS-related parameters during the three match periods.

However, our particular study did not provide a clear distinction between the possible influence of CHO and fat on the activation of the SNS and PNS over different match periods of badminton players. In most cases, HRV parameters related to PNS or SNS activation before, during, or after matches were either negatively or positively influenced by the intake of fat and CHO. However, the direction of the influence did not stay constant between different match periods. Differences in substrate metabolism due to changes in exercise intensity during different match periods may serve as one of the reasons for the variation in the influence of macronutrient consumption on HRV parameters over different match periods. For instance, researchers observed that most of players' energy during a match is provided by the aerobic energy system (60-70%), while only 30% is obtained from the anaerobic system (44). In terms of the anaerobic system, the alactic

anaerobic system contributes the most to muscle energy delivery, followed by the lactic anaerobic energy system that provides less energy (44). The use of the anaerobic energy system during match play places a greater demand on the utilization of CHO through glucose metabolism during particularly high-intensity periods of the match. However, the storage capacity of CHO is very limited (typically 400-800g) and is regulated carefully during and after high-intensity exercise, as the replenishment of this substrate after depletion is a high metabolic priority (27). In this regard, the execution of aerobic activities during periods between high-intensity periods will cause changes in substrate metabolism, which leads to lower muscle and liver glycogen levels (27). In such instances, due to the increase in energy demands during aerobic exercise, the decrease in muscle and liver glycogen levels may act as a stimulus for obstructing glycogen availability, which will bring about a compensatory drive to increase energy intake after exercise to restore availability demands (27).

The central nervous system is responsible for maintaining normal concentrations of glucose levels and delaying the process of muscle glycogen depletion during exercise (5). Therefore, a higher CHO intake in the periods before exercise or match participation will cause a delay in glycogen depletion as a result of the maintenance of blood glucose concentrations late into exercise (25). Moreover, the intake of CHO will also help facilitate skeletal muscle contractions since the muscle is the largest depot of glycogen storage (37). These benefits of a higher CHO intake will delay the onset of fatigue and allow participants to maintain a more favorable ANS milieu for the achievement and sustainment of a high-performance level during match participation.

On the other hand, findings show that the intake of micronutrients influences HRV more during different match periods than the intake of macronutrients. As mentioned before, calcium was identified as the primary micronutrient to influence the HRV-related parameters during the pre- and in-match periods, whereas potassium had the biggest influence during the post-match period and the second biggest influence on HRV during the pre-match period. Calcium is a mineral that plays a crucial role in regulating various functions such as HR, muscle contractions, nerve impulses, and energy metabolism which include the metabolism of lipid and glucose (47). In particular, calcium is involved in the activation and regulation of smooth and skeletal muscle contractions via the calcium channels (19,36). Research also suggests that calcium could be involved in sympathetic nervous system activation by giving rise to insulin resistance and hyperinsulinemia (28). Potassium, on the other hand, is essential for the regulation of fluid, acid, and the electrolyte balance of the body, as well as for normal cell functioning (1). Since the body

is inclined to bring all physiological systems back to the pre-exercise homeostatic state directly after exercise, this may explain why a mineral involved with especially fluid, acid, and electrolyte balance could play a more important role during the post-match period, in comparison to in-match periods.

Our results further indicated that vitamin D, together with boron, contributed to changes in the HRV-related parameters during the pre-match period. However, none of these micronutrients was identified as major contributors to changes in HRV during the in- and post-match periods. Vitamin D is essential for signalling processes and cell functioning and helps to regulate the transfer of glucose to the brain (6,15), while boron is crucial for brain functioning, estrogen and testosterone production, and the absorption of calcium and magnesium components (45). The latter is an important trace mineral with diverse roles, which beneficially impacts the body's use of vitamin D (45). In this regard, healthy males showed significant increases in free testosterone and levels of vitamin D, cortisol, and dihydrotestosterone, as well as a decrease in inflammatory biomarkers after one week of boron supplementation (39). The fact that vitamin D and boron only served as major contributors to changes in HRV parameters during the pre-match period would suggest that these micronutrients are especially involved during the preparation and activation of physiological systems for exercise or match play.

An unexpected finding of this study is the non-significant canonical correlation between the 24-hour, in-competition macronutrient intake and the post-match HRV-related variables of the badminton players, despite a rather higher canonical correlation of 0.97 between the last-mentioned variables. Even though a log transformation was used to improve the normality of HRV data, the results in Table 2 suggest that the majority of HRV parameters obtained very high standard deviation values for the post-match period, which indicates a high variability in HRV parameter values between individuals. The fact that canonical correlation analysis does not make strong normality assumptions means that outliers may have caused non-significant results (41). Moreover, the variability in post-match HRV values would also imply that the HRV response of individuals to a specific match demand, varies a great deal. In this regard, Buchheit (8) alluded to fact that the measurement and analyses of HRV values in exercise settings are more complex due to the dependency of HRV on exercise intensity. Therefore, the different intensities of matches, playing styles, and tactics of players will have a direct influence on their HRV values (30).

In conclusion, although all the canonical correlation analyses revealed strong correlations between 0.93 and 0.99, as well as canonical functions that accounted for between 80.44% and 98.01% of the total variation between the two canonical roots, the canonical correlation between the 24-hour, in-competition macronutrient intake and the post-match HRV-related variables of badminton players was non-significant. However, results also showed that 53.14%, 46.82%, and 51.57% of the variance in the respective pre-, in-, and post-match HRV-related variables could be accounted for by the macronutrient-related variables. Trans fatty acids followed by available CHO, were the macronutrients that had the biggest influence on changes in HRV parameters over the different match periods. Added sugars were identified as the third most influential macronutrient in terms of the in- and post-match periods, while total sugars served as the third most contributing macronutrient to pre-match HRV changes. However, there was no clear distinction between the direction of the influence of CHO and fat on the activation of the SNS and PNS over different match periods, as PNS- and SNS-related HRV parameters were either negatively or positively influenced by the intake of these macronutrients. Therefore, the following hypotheses were rejected: Firstly, a 24-hour low-CHO diet will lead to significantly higher SNS-related pre-, in- and post-match HRV values of badminton players compared to a high-CHO diet; secondly, a 24-hour low-CHO diet will lead to significantly lower PNS-related pre-, in- and post-match HRV values of badminton players compared to a high-CHO diet.

Overall, results also revealed that calcium, potassium, vitamin D, and boron were the micronutrients that contributed most meaningfully to pre-match HRV changes. Furthermore, while calcium was identified as the only micronutrient to have a meaningful contribution to HRV during the in-match period, potassium was distinguished as the only micronutrient that influenced post-match HRV changes meaningfully. Again, there was no clear distinction between the direction of the influence of the different micronutrients on the activation of the SNS and PNS over different match periods, as PNS- and SNS-related HRV parameters were either negatively or positively influenced by the intake of these micronutrients. Therefore, the hypothesis that a 24-hour diet intake containing mineral- and vitamin-related components will lead to significantly higher SNS-related pre-, in-, and post-match HRV values of badminton players, was also rejected.

Although all the hypotheses were rejected, it should be noted that since earlier research did not investigate the effects of dietary intake on the parameters of HRV during different periods of a real-life badminton competition, the findings of this study provide necessary insight into an area of research where uncertainty remains. However, results must be interpreted with caution since

relationships between the different sets of variables were only determined for badminton players from Africa. Although studies of specifically defined groups allow researchers to develop their knowledge concerning a certain research theme, the strength and nature of the relationships between short-term diets and HRV parameters should be tested and measured through longitudinal studies among different populations of athletes. In addition, while real-life studies provide information that better represent the aspects that sport-related professionals deal with during their everyday lives, the randomization of participants into control and experimental groups remain the most effective method to evaluate the possible influence of specific quantities of macro -and micronutrients on the various HRV parameters. Nonetheless, time and logistical constraints, as well as the unwillingness of players to change their diets during in-competition periods, may make the implementation of the recommended methodology difficult.

PRACTICAL APPLICATIONS

The study's findings indicate that short-term in-competition diets that include, in particular, trans fatty acids, CHO, added sugars, total sugars, calcium, and potassium, will meaningfully influence changes in HRV parameters over different periods of a real-life badminton competition. In addition, the match-period-specific influences suggest that sport-related professionals should ensure that players ingest sufficient amounts of vitamin D and boron before the start of a competition since these micronutrients influence pre-match HRV values. Nonetheless, while more research is needed to confirm the possible influence of diet-related components on HRV and related ANS functioning, the results of this study highlight the importance of managing athletes' in-competition diets to ensure optimal functioning of the ANS during competition participation.

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CHAPTER 4

ARTICLE 2:

RELATIONSHIPS BETWEEN 24-HOUR DIET AND THE IN- AND POST-MATCH HEART RATE RECOVERY OF BADMINTON PLAYERS

This article was submitted to the *International Journal of Sports Medicine* and is currently under review.

ABSTRACT

The purpose of this study was to determine the relationships between 24-hour diet and the in- and post-match heart rate recovery (HRR) of badminton players. The HRR of 20 players was measured during, and after 46 badminton matches by using fixed Polar heart rate transmitter belts and monitors. A 24-hour diet recall questionnaire in an interview format was used to determine the current in-competition diets of participants. The canonical correlation for the relationships between micronutrient components, and the in- and post-match HRR-related variables of participants were significant ($R = 0.92$, $p = 0.03$), whereas the relationship between macronutrients, and the in- and post-match HRR of participants were non-significant ($R = 0.84$, $p = 0.10$). Overall, carbohydrate availability, total sugars, added sugars, and trans-fatty acids were the macronutrients that had the biggest influence on changes in HRR-related variables over the two match periods. Furthermore, the results revealed that vitamin D, calcium, and potassium were the micronutrients that contributed meaningfully to in- and post-match HRR changes of participants. Therefore, the results of our study highlight the importance of managing athletes' in-competition diets to ensure optimal functioning of the autonomic nervous system during competition participation.

KEYWORDS: short-term diet, macronutrients, vitamins, and minerals, cardiac control, competition

INTRODUCTION

Heart rate (HR) is regarded as one of the most valuable and widely used physiological variables in sport and exercise settings [17, 23]. Heart rate recovery (HRR), which is the absolute (in beats per minute (bpm)) or relative HR decrease (in percentage) over a certain time after moderate to heavy-intensity exercise, is commonly used as an indicator of cardiovascular fitness [16, 43]. However, most researchers agree that the main mechanism underlying the exponential cardio-deceleration after exercise is parasympathetic activation and sympathetic withdrawal [5, 7, 51]. Therefore, HRR can be used as a simple and non-expensive measurement to evaluate the functioning of the cardiac autonomic nervous system (ANS) after exercise, and as an indicator of training status and sport performance [7, 12, 19]. Nevertheless, until now, only a few researchers have investigated the autonomic markers of HR, such as HRR, during and after a live sports event [6, 23, 25]. Furthermore, despite proof that autonomic cardiac control is influenced by several factors, such as short-term (24-hour) diet, only a limited number of studies have investigated the possible influence of diet on ANS control [11, 26, 36].

In general, athletes who experience less fatigue and recover faster are fitter; thus, they experience physiological and psychological adaptations at a more rapid rate than athletes who experience more fatigue and recover slower [17]. Since HRR serves as an indicator of recovery after exercise, it is not surprising that the exponential improvements in HRR due to training are significantly related to increases in certain performance indicators [25, 32, 49]. For example, HRR improved significantly after four weeks of high-intensity training (7 ± 6 beats per minute; $p = 0.001$), in well-trained cyclists [32]. Also, significant relationships were found between HRR, peak power output ($r = 0.73$, $p < 0.001$) and 40-km time-trial performance ($r = 0.96$, $p < 0.0001$), respectively [32]. Furthermore, significant relationships were observed between HRR, $\dot{V}O_{2\max}$ (maximum oxygen intake during exercise) ($r = 0.51$, $p < 0.039$) and volume of physical activity ($r = 0.67$, $p < 0.003$) in well-trained endurance athletes [34].

Team-sport athletes with a faster HRR may also be better suited for higher intensity activities where opposition players must, for example, be marked, and, high-pressure situations during match play must be handled [25]. In this regard, basketball players, who were classified as more fit, exhibited a faster HRR at 60 seconds after a sport-specific exercise, reached higher $\dot{V}O_{2\text{peak}}$ values during a performance test at the start of the season, and improved their cardiac autonomic control more throughout the season compared to players that were classified as less fit [23]. A comparison between the HRR of elite and sub-elite table tennis players showed that the 60 second

HRR of elite players was significantly faster (difference of ± 8 beats at 60 sec, $p < 0.05$) after maximal table tennis-specific tests than their sub-elite counterparts [17]. Therefore, the last-mentioned findings suggest that athletes with higher aerobic fitness levels who compete at a higher level, recover faster after sport-specific exercise, as indicated by their better HRR profiles, in comparison to their less fit and lower-level counterparts [17, 25, 32].

Although the above-mentioned findings verify the value and usability of HRR in sport and exercise settings, a range of factors influence ANS-related HR values when measured during sport-specific training and competition participation [4, 36, 49]. One of these is the short-term diets of athletes [26, 35, 36]. Although no studies have investigated the influence of short-term diet on the HRR of participants, previous research did focus on the possible influence of a short-term diet on the heart rate variability (HRV) of participants. For example, a group of endurance cyclists who consumed a high-fat diet (68% of total energy from fat) for 6 days, followed by one day of carbohydrate (CHO) loading (90% of total energy from CHO), experienced a significant increase ($p < 0.05$) in pre-exercise normalised low-frequency (LF) power values compared to when they consumed a high-CHO diet (68% of total energy from CHO) [26]. Researchers also observed a significant decrease ($p < 0.05$) in the mean value of normalised high-frequency (HF) power in a group of males during a progressive, incremental cycling protocol test, after they ingested a low-CHO diet (10% CHO, 35% lipids, and 55% protein), compared to the intake of a high-CHO diet (80% CHO, 10% lipids, and 10% protein) [35]. In contrast, the mean normalised LF power value revealed a significant increase ($p < 0.05$) after the intake of the low, compared to a high-CHO diet [35]. Consequently, the LF/HF ratio increased significantly ($p < 0.05$) in the low-CHO diet, compared to their high-CHO diet counterparts [35]. In another study, the HRV indices (LF and HF powers, the standard deviation of instantaneous beat-to-beat interval variability (SD1), and the standard deviation of continuous long-term beat-to-beat interval variability (SD2)) of men did not change significantly during a moderate-intensity cycling exercise due to CHO availability [36]. However, absolute HF and LF, SD1 and SD2 values at five minutes and exhaustion during a severe-intensity cycling exercise increased significantly ($p < 0.05$) for the low-CHO group (10% of total energy from CHO, 55% of total energy from protein, 35% of total energy from fat), compared to the moderate-CHO diet group (65% of total energy from CHO, 15% of total energy from protein, 20% of total energy from fat) [36].

Researchers found that certain micronutrients, such as calcium, vitamin D, and dietary sodium, also influenced ANS function [2, 50]. For example, Allen et al. [2] reported an increase in

sympathetic nervous system (SNS) activity as showed by the increase in normalised low-frequency powers (LFnu) and a decrease in the standard deviation of all normal-to-normal intervals (SDNN), the mean squared differences between successive R-R intervals (RMSSD), as well as the high-frequency relative power expressed as normalised units (HFnu) when participants were subjected to a low-sodium diet. Furthermore, the researchers found that the ingestion of calcium and vitamin D supplements increased SNS activity, giving rise to norepinephrine release and higher heart response in healthy participants [50]. These observations strongly suggest that healthy participants will experience an increase in SNS activity after the consumption of the last-mentioned vitamin and mineral-related components [2, 50].

Overall, these findings indicate that the activity of the sympathetic and parasympathetic branches of the ANS during severe-intensity exercise and rest can be influenced by dietary manipulation, especially when the CHO dietary intake is manipulated [26, 35, 36]. Despite proof of the influence of short-term diet on ANS control, no studies have thus far investigated this influence during actual, real-life competitions. Instead, these studies investigated the influence of diet on ANS control through laboratory-based protocols instead of actual competitions [26, 35, 36]. The high pressure that comes with real-life competitions and the resulting stress will automatically bring about sympathetic predominance, which ultimately may influence changes in ANS control [14, 20, 22]. Therefore, laboratory-based protocols may not provide an accurate picture of changes in the ANS profile of athletes during real-life competitions. Furthermore, the above-mentioned studies manipulated the diets of participants instead of evaluating the influence of their normal short-term diets on ANS control [26, 35, 36]. Consequently, the purpose of this study was to determine the relationships between 24-hour diet and the in- and post-match HRR of badminton players. The outcome of this study will provide researchers, sports scientists, and coaches with direction concerning the influence of different components of a normal short-term, in-competition diet on the HRR values of badminton players.

MATERIALS AND METHODS

Participants

The sample consisted of 21 male, African, singles-badminton players (23.3 ± 3.9 years; height: 177.1 ± 3.0 cm; mass: 83.4 ± 14.5 kg) who were injury-free, actively involved in, and competing as members of their respective teams and national badminton federations in relevant badminton championships, participated in the study. The championships can be listed as follows: The All-African Badminton Senior Championships, the South African International Championships, the

Free State National Championships, the u/19 South African National Championships, and the University Sport South Africa (USSA) Badminton Championships. The sample of participants represented ten African countries, namely Botswana, Cameroon, Congo, Egypt, Namibia, Nigeria, South Africa, Uganda, Zambia, and Zimbabwe. Participants were monitored during, and directly after, 46 matches. In general, their competitive badminton playing experience ranged between 4 and 12 years (9.5 ± 2.7 years). The following information concerning the training regimen of participants was also obtained: participants trained for 4 ± 1 day a week that consisted of on-court training for 4 ± 1 day a week and weight training for 2 ± 2 days a week. One participant's post-match HRR (%) could not be measured; therefore, only 20 participants' data were used in the study. The study procedures were approved by the Health Research Ethics Committee of the institution where the research was conducted (NWU-00199-14-A1-04). The study was conducted according to the ethical guidelines and principles of the International Declaration of Helsinki, the ethical guidelines of the National Health Research Ethics Council of South Africa, and the ethical standards of the International Journal of Sports Medicine [24]. Permission to conduct the research was obtained from the Badminton World Federation (BWF), the Badminton Confederation of Africa (BCA), the Botswana Badminton Association (BBA), and Badminton South Africa (BSA).

Study design

A selected group, repeated measures, observational, descriptive, and an *ex post facto* design was used for this study. On the first day of every championship, informed consent was obtained from participating players. They then completed a general information questionnaire regarding their exercising habits, injury incidence, and competitive level. Their stature and body mass measures were determined thereafter. Next, the participants were fitted with a fixed Polar HR transmitter belt and a Polar HR monitor (Polar Team2 Pro, Polar Electro, Kempele, Finland), five minutes before each match warm-up. This was done to record the participants' HR every second during, and for one minute after, each match. The warm-up period allowed the researchers to check the signals of HR monitors and participants could familiarise themselves with the equipment and HR transmitter belts. A video camera (Sony HDR-PJ790VE Handycam, Sony Corporation, Tokyo, Japan) was stationed on a tripod behind each of the courts where matches were played on. The video footage from matches was used to determine the length of each match so that researchers were able to set the correct duration for HR analysis. The HRR of participants was measured during, and after 46 matches. Each participant was, therefore, measured twice, although several participants were measured three times. All championships took place over two to three days, which meant that participants were monitored and measured on consecutive days. The exception

was the Free State National Championships, which transpired over only one day. The research team used the 24-hour diet recall questionnaire to interview each participant individually during the tournaments. A digital mp3 recorder (Olympus VN-5500) was used to record every interview to capture the relevant information about the in-competition diet preferences of each participant.

Demographic and general information questionnaire

A questionnaire was used to collect demographic and personal information of all participants. It obtained information on the individual ages, exercising habits, injury history, competitive levels, and the highest achievements of participating players. Each participant was also expected to indicate whether they were taking any form of medication during the tournament.

Anthropometric measurements

Body mass was recorded to the nearest 0.1 kg, using a calibrated BFW 300 Platform scale (Adam equipment Co. Ltd., U.K.), and body stature to the nearest 0.1 cm, using a Harpenden portable stadiometer (Holtain Ltd., U.K.). The latter measurements were used to describe the specific cohort of participants.

Heart rate and heart rate recovery

The HR of each player was recorded using a fixed Polar HR transmitter belt at 1-second intervals throughout each match and for one minute after each match. Heart rate values (HRV) were used to determine participants' minimum, average, and maximum HRs during matches. Subsequently, these particular measurements were used to calculate HRR by determining the absolute value at 60 seconds, i.e., HR at one-minute recovery subtracted from the HR immediately after a set or the match. The 60-sec HRR, as a percentage decline, was also calculated by dividing participants' HR at one-minute recovery by their HRs immediately after the set or match, multiplied by 100. However, in cases where a participant's post-set or post-match HR did not obtain a value above 85% of his theoretical maximal HR ($208 - 0.7 * \text{age}$), the HRR measurement was discarded [7, 13]. The reason that the period of 60 seconds was used for the determination of HRR, is that researchers regard 60 second HRR to be an accurate measure of parasympathetic reactivation [13]. As previously mentioned, video recordings of each match were downloaded onto a laptop and used to determine the correct periods and durations for HR analysis.

The twenty-four in-competition diet

A 24-hour diet recall questionnaire in an interview format was used to determine the current in-competition diets of participants. The 24-hour recall is aimed to determine the food eaten over the past 24 hours; it takes into consideration cooking methods and quantities. Therefore, each participant was required to recall all food and beverages they consumed during the previous 24 hours. Special prompts were used to determine their food consumption during the competition period if they had competed the previous day. The interviews, lasting 30 minutes each, were conducted on the competition day at a time that suited each participant. Moreover, they were conducted by a qualified sports scientist trained by a qualified dietician to obtain dietary data. Interviews were structured with specific probes to help participants remember all the foods they had consumed throughout the relevant 24-hour period. Plastic food models, food picture books, as well as household measures, were used to improve the accuracy of identifying portion sizes. Every interview was recorded using a digital voice recorder so that the interviewer could revert to the recording if any of the records were unclear.

All recorded food items were manually coded in Excel® by the researchers, using the Food Composition and Quantity Manuals (South African Medical Research Council, 2019). The food recalled in household measures was converted to grams and millilitres. Data accuracy was ensured by identifying outliers (very high or very low amounts) and then verifying the different values through rechecking of the original documentation and audio recordings. Spot checks were also performed on the codes to ensure that data was coded correctly. Once the data were deemed accurate, it was transferred by manually entering the food codes and weights into FoodFinder for Windows, software developed by the South African Medical Research Council (SAMRC) [31, 54]. FoodFinder was used to calculate the energy and nutrient intake of the participants. After the data were analysed by using this software package, it was exported into an Excel® sheet where it was again checked for any inaccuracies. In addition, these data were verified against the originally captured data to ensure that food quantities were captured correctly, and accurately reflected the energy intake and the types of food consumed over the 24-hour time period. Moreover, the total energy intake and energy intake per meal (breakfast, lunch, dinner, and in between meals) were calculated. The macronutrients (CHO, protein, and fat) consumed were also calculated as a percentage of the total energy intake.

Several researchers had previously made use of the 24-hour diet recall questionnaire to conduct competition-day diet assessments of sport participants [10, 21]. In general, researchers agree that

the immediacy of the recall period enables participants to recall most of their dietary intake, which makes the 24-hour recall more accurate than other measuring instruments [48]. In this regard, researchers reported better measurement properties for 24-hour dietary recalls compared to food frequency questionnaires for both absolute and relative energy and protein intake [29, 46]. The 24-hour diet recall questionnaire is regarded to be the least biased self-report instrument; and, thus, it is useful for most research purposes [48].

Statistical analysis

The Statsoft Statistical Data Processing Package was used to process the data. In the first step, each variable's descriptive statistics (minimum and maximum values, averages, and standard deviations) were calculated. Next, tree clustering, single-linkage cluster analysis, using as similarity measure $1-r$, with r being the Pearson correlation coefficient between two variables, of all diet-related variables were performed to detect clusters of variables (measures) that are related to each other [53]. Linkage distance for the detection of different clusters was set at 0.2. The cluster analysis reduced variables were entered into canonical correlation analysis [41]. The results of several diet-related variables (the first set of variables) were canonically correlated to in-match rest and post-match HRR (second set of variables), respectively. The level of significance for all analyses was set at $p \leq 0.05$. As part of the canonical correlation analysis, canonical loadings were also calculated since they are preferred because of the deficiencies inherent to canonical weights. Canonical loadings are not affected by multi-collinearity because the loading of each variable onto its canonical dimension is calculated in the presence of all other contributing variables to the same canonical dimension [30]. The canonical loadings allow researchers to assess the relative contribution of each variable to each canonical function [30]. Only loadings that were greater than, or equal to 0.30, contribute meaningfully to the multivariate relationship and were accepted [52].

RESULTS

The descriptive statistics of the badminton players' HR and HRR-related variables for different match periods are displayed in **Table 1**.

Table 1: Descriptive statistics of HR- and HRR-related variables of players.

HR- and HRR-related variables	Values (mean $\pm$ SD)
HR-related variables	
Match HR minimum (bpm)	116.43 $\pm$ 28.99
Match HR average (bpm)	172.19 $\pm$ 11.53
Match HR maximum (bpm)	197.14 $\pm$ 8.93
HRR-related variables	
Absolute in-match HRR (bpm)	23.01 $\pm$ 7.86
Relative in-match HRR (%)	12.78 $\pm$ 4.73
Absolute post-match HRR (bpm)	27.40 $\pm$ 12.60
Relative post-match HRR (%)	14.34 $\pm$ 6.16

* All values are mean $\pm$ SD; HR = heart rate; HRR = heart rate recovery; bpm = beats per minute

Participants obtained an average in-match HR of 172 ($\pm$ 11.53) bpm. Furthermore, they obtained a high in-match maximal HR of 197 ($\pm$ 8.93) bpm, while the HRR results show that they obtained a higher average post-match HRR (27.40 $\pm$ 12.60 bpm), in comparison to the average in-match HRR value (23.01 $\pm$ 7.86 bpm). The participants achieved relative HRR values of 12.78 $\pm$ 4.73% and 14.34 $\pm$ 6.16% for the in- and post-match HRR values, respectively.

Table 2 presents the descriptive statistics of all diet-related variables (macronutrients and vitamins) consumed by participants over a 24-hour, in-competition time period.

Table 2: Descriptive statistics of macronutrient and vitamin-related components of players.

Energy and macronutrients	Values (mean $\pm$ SD)	Vitamins	Values (mean $\pm$ SD)
Energy (kJ)	10 467.48 $\pm$ 3733.45	Vitamin A (mcg)	531.95 $\pm$ 515.40
Total protein (g)	85.90 $\pm$ 38.11	Vitamin B6 (mg)	2.10 $\pm$ 1.22
Total protein (%)	15.69 $\pm$ 4.46	Vitamin B12 (mcg)	2.05 $\pm$ 1.88
Plant protein (g)	21.48 $\pm$ 8.66	Vitamin C (mg)	79.48 $\pm$ 112.23
Animal protein (g)	63.57 $\pm$ 33.21	Vitamin D (mcg)	4.71 $\pm$ 3.45
Total fat (g)	100.76 $\pm$ 44.54	Vitamin E (mg)	10.57 $\pm$ 5.84
Total fat (%)	39.07 $\pm$ 7.52	Vitamin K (mcg)	47.57 $\pm$ 36.24
Saturated fat (g)	23.52 $\pm$ 10.38	Retinol (mcg)	124.48 $\pm$ 96.34
Mono-unsaturated fats (g)	27.14 $\pm$ 10.86	Niacin (mg)	23.05 $\pm$ 10.92
Polyunsaturated fats (g)	31.95 $\pm$ 23.36	Pantothenate (mg)	1.90 $\pm$ 1.79
Total trans-fatty acids (g)	1.38 $\pm$ 2.01	Biotin (mcg)	26.81 $\pm$ 8.39
Cholesterol (mg)	443.05 $\pm$ 185.30	A-Tocopherol (mg)	4.95 $\pm$ 3.60
Available carbohydrates (g)	267.14 $\pm$ 116.95	Folate (mcg)	270.71 $\pm$ 95.55
Available carbohydrates (%)	45.24 $\pm$ 8.48	Total carotenoids (mcg)	1086.24 $\pm$ 2357.61
Starch (g)	57.62 $\pm$ 61.16	Cryptoxanthin (mcg)	24.24 $\pm$ 26.15
Glucose (g)	2.86 $\pm$ 3.35	B-Carotene (mcg)	909.86 $\pm$ 1950.94
Fructose (g)	5.24 $\pm$ 6.88	A-Carotene (mcg)	298.90 $\pm$ 755.58
Sucrose (g)	9.52 $\pm$ 9.55	Oxalic acid (mg)	27.10 $\pm$ 39.89
Lactose (g)	2.10 $\pm$ 3.74	Lutein (mcg)	104.76 $\pm$ 98.17
Total sugars (g)	22.86 $\pm$ 21.29	Lycopene (mcg)	432.52 $\pm$ 507.99
Added sugar (g)	58.67 $\pm$ 31.82		
Leucine (g)	2.62 $\pm$ 2.77		
Lysine (g)	2.48 $\pm$ 2.54		
Arginine (g)	2.19 $\pm$ 1.75		
Alanine (g)	1.86 $\pm$ 1.71		
Aspartic acid (g)	4.48 $\pm$ 3.36		
Glutamic acid (g)	9.24 $\pm$ 5.64		

* All values are mean $\pm$ SD; kJ = kilojoules; g = grams; mg = milligrams; mcg = micrograms

The tabulated results show that participants, on average, consumed 10 467.48kJ of food over the 24-hour competition period. The average protein intake was 85.90 g and consisted mainly of animal protein (63.57 g). The average total fat intake was 100.76 g, of which poly-unsaturated fats were the primary component (31.95 g). Participants ingested, on average, 267.14 g of CHO, of which sucrose formed the main component (9.52 g). The amino acids that obtained the highest intake values were glutamic acid (9.24 g) and aspartic acid (4.48 g). Overall, protein made up 15.69% of their total macronutrient intake, while total fat made up 39.07%, and carbohydrates

45.24%. An analysis of the average 24-hour vitamin intake showed that vitamin C was most consumed (79.48 mg), followed by oxalic acid (27.10 mg), niacin (23.05 mg), and vitamin E (10.57 mg), respectively.

Table 3 indicates all the micronutrient, mineral-related components consumed by participants over the relevant 24 hours.

Table 3: Descriptive statistics of micronutrient and mineral-related components of players.

Minerals	Values (mean $\pm$ SD)
Calcium (mg)	379.81 $\pm$ 228.85
Iron (mg)	9.00 $\pm$ 3.51
Magnesium (mg)	255.90 $\pm$ 108.65
Phosphorus (mg)	1271.38 $\pm$ 515.57
Potassium (mg)	2723.62 $\pm$ 1403.99
Sodium (mg)	2633.38 $\pm$ 1027.60
Chlorine (mg)	1650.86 $\pm$ 855.35
Zinc (mg)	7.57 $\pm$ 4.97
Chromium (mcg)	32.29 $\pm$ 21.09
Selenium (mcg)	47.81 $\pm$ 13.41
Manganese (mcg)	1594.33 $\pm$ 863.16
Iodine (mcg)	70.00 $\pm$ 27.99
Boron (mcg)	457.29 $\pm$ 286.99
Phytate (mg)	377.86 $\pm$ 209.95
Malic acid (mg)	461.67 $\pm$ 479.99
Citric acid (mg)	491.24 $\pm$ 615.50

* All values are mean $\pm$ SD; mg = milligrams; mcg = micrograms

Table 3 shows that potassium (2723.62 mg), sodium (2633.38 mg), chlorine (1650.86 mg), and phosphate (1271.38 mg) are the minerals that were consumed the most during the 24 hours.

In an attempt to first identify the diet-related variables that were related to each other and to retain only the relevant variables for the canonical correlation analyses, cluster analysis were performed. The first cluster analysis reduced the 24 macronutrient variables for the in-competition period to the following seven variables: Total protein, total trans-fatty acids, cholesterol, available carbohydrates, lactose, total sugars, and added sugars. Another cluster analysis reduced the 36 vitamin- and mineral-related components to the following nine variables: Calcium (Ca), potassium (K), zinc (Zn), chromium (Cr), selenium (Se), iodine (I), boron (B), vitamin C, and vitamin D.

Since the researchers only focused on the relationships between the components of a 24-hour diet (predictor variables) and the HRR (outcome variables) of participants, only the canonical correlation analysis results that are related to this purpose, are reported.

THE RELATIONSHIP BETWEEN MACRONUTRIENT-RELATED COMPONENTS AND HRR

In the first canonical correlation analysis, the canonical analysis reduced variables were included to determine the relationship between macronutrient- and HRR-related variables. The HRR-related variables used for this were the average, relative in- and post-match HRR values. The results of the analysis are presented in **Table 4**.

Table 4: Canonical correlation analysis between macronutrients and HRR-related variables of players.

	Canonical correlation (R): 0.84; Chi²(14) = 20.98; p = 0.10	
	Left	Right
Number of variables	7	2
Variance extracted	38.59%	100.00%
Total redundancy	22.91%	62.46%
Variables: 1	Total protein (g)	Post-match HRR (%)
2	Total trans-fatty acids (g)	Average HRR during in-match (%)
3	Cholesterol (mg)	
4	Available carbohydrates. (g)	
5	Added sugar (g)	
6	Total sugars (g)	
7	Lactose (g)	

*g = grams; mg = milligrams; HRR = heart rate recovery

A strong non-significant canonical correlation of 0.84 ($p = 0.10$) was found between participants' macronutrient intake and their relevant in- and post-match HRR-related variables. The canonical function accounted for a total variation of 70.56% ($r^2 \times 100$) between the two variants. The variance extracted values showed that 100% of the variance could be extracted from the right set, and 38.59% from the left set of variables, respectively. The total redundancy values showed that 62.46% of the variance in the in- and post-match HRR parameters, could be accounted for by the seven macronutrient-related variables. The canonical loadings revealed that the macronutrient-related variables contributing the most to the relationship during the last-mentioned periods were available carbohydrates (g) (0.93), total sugars (g) (0.65), total trans-fatty acids (g) (-0.55), and

added sugars (g) (0.49). Finally, the HRR-related variable scores revealed canonical loadings of -0.99 and -0.81 for the in- and post-match periods, respectively.

The relationship between micronutrient-related components and HRR

In the second canonical correlation analysis, the relationship between the nine micronutrients and the in- and post-match HRR-related variables was determined. The results of this analysis are displayed in **Table 5**.

Table 5: Canonical correlation analysis between micronutrients and HRR-related variables of players.

	Canonical correlation (R): 0.92; Chi²(18)=31.49; p = 0.03	
	Left	Right
Number of variables	9	2
Variance extracted	18.84%	100.00%
Total redundancy	12.26%	58.17%
Variables: 1	Calcium (mg)	Average HRR during in-match (%)
2	Potassium (mg)	Post-match HRR (%)
3	Zinc (mg)	
4	Chromium (mcg)	
5	Selenium (mcg)	
6	Iodine (mcg)	
7	Boron (mcg)	
8	Vitamin C (mg)	
9	Vitamin D (mcg)	

*mg = milligrams; mcg = micrograms; HRR = heart rate recovery

The analysis revealed a strong significant canonical correlation of 0.92 ($p = 0.03$) between participants' micronutrient intake and their related in- and post-match HRR-related variables. The canonical function accounted for a total variation of 84.64% ($r^2 \times 100$) between the two canonical variants. The variance extracted values showed that 100% of the variance could be extracted from the right set, and 18.84% from the left set, respectively. The total redundancy values showed that, on average, 58.17% of the variance in the in- and post-match HRR parameters, could be accounted for by the nine micronutrient-related variables. Furthermore, the canonical loadings indicated that the micronutrient-related variables contributing most to the relationship during the last-mentioned periods were vitamin D (mcg) (-0.58), calcium (mg) (0.41), and potassium (mg) (0.39). Lastly, the

HRR-related variable scores revealed canonical loadings of -0.80 and -0.21 for the in- and post-match periods, respectively.

DISCUSSION

To our knowledge, this is the first study to investigate the effects of a 24-hour diet on HRR-related variables during different periods of an actual, real-life competition. Furthermore, it is the first to extensively evaluate the 24-hour in-competition diet profiles of African, male, badminton players. However, the purpose of this study was not to analyse and compare the dietary profiles of players according to the prescribed dietary guidelines; but rather, to determine the relationship of diet and dietary components to HRV. Consequently, we will not discuss any dietary-guideline related comparisons.

The canonical correlation analyses of the relationships between the 24-hour diet-related components and the in- and post-match HRR-related variables revealed the following results: the correlation values of $R = 0.84$ ($p = 0.10$) for the macronutrients and $R = 0.92$ ($p = 0.03$) for the micronutrients. To summarise, the first canonical correlation analysis revealed a strong non-significant correlation, while the second canonical correlation analysis revealed a strong significant canonical correlation. Consequently, canonical functions accounted for between 70.56%, and 84.64% of the total variation between the two canonical roots. Overall, results also showed that the seven macronutrients accounted for 62.46%, whereas the nine micronutrients accounted for 58.17% of the variance in the in- and post-match HRR values.

In further analysis, the canonical loadings were calculated for each of the diet and HRR-related variables. The analysis revealed that an increase in participants' consumption of available carbohydrates (CHO), total sugars, and added sugars influenced both their, in- and post-match HRR values negatively. The latter also identified available CHO and total sugars as the macronutrients with the greatest influence on HRR, during both aforementioned match periods. In contrast to this, the consumption of trans-fatty acids had a positive influence on these variables. In terms of the relevant micronutrients, an increase in participants' consumption of calcium and potassium had a negative influence on their HRR, whereas vitamin D had a positive influence. Moreover, the latter was identified as having the greatest influence on participants' HRR during the two match periods, in comparison to other micronutrients. Finally, the canonical loadings for the HRR-related variables were much higher for the macronutrient relationships (in-match HRR: -0.99; post-match HRR: -0.81) than for the micronutrient relationships (in-match HRR: -0.81;

post-match HRR: -0.21). Therefore, both canonical correlation analyses, indicated that the loadings were highest for participants' in-match HRR.

As previously mentioned, no other studies have investigated the influence of short-term diet on the HRR of participants. Consequently, it is difficult to draw a direct comparison between the results of the current study and other studies. However, several studies have investigated the influence of CHO consumption on HRV control and found that low-CHO diets increased SNS activity, while high-CHO diets maintained ANS control [26, 35]. For instance, two earlier studies reported that participants showed significant increases in LF after following a low-CHO diet [26, 35]. Similarly, significant increases in SNS activity were observed in a group of healthy males who were subjected to a low-CHO diet [36]. The same researchers also found that diets containing CHO influenced HRV parameters during high-intensity, but not during moderate-intensity exercise [36]. In addition, another study by Tentolouris et al. [47] revealed that both lean and obese individuals experienced an increase in SNS activity as well as plasma norepinephrine levels after they had followed a high-CHO iso-energetic diet. Similarly, our results revealed that CHO-containing macronutrients had a large, significant negative influence on participants' in- and post-match HRR. A possible explanation for this result is that a small increase in glucose, together with an increase in insulin that occurs with the intake of CHO, will stimulate glucose metabolism in the cells of the ventromedial hypothalamus, thereby suppressing the inhibitory pathway, resulting in an increase in SNS activity [33].

In contrast to the influence of CHO and sugar intake, HRR values were positively influenced by the intake of trans-fatty acids. A previous study indicated that eight well-trained cyclists who ingested a high-fat diet (68% of total energy from fat) experienced an increase in the SNS activity during endurance training, which included high-intensity sprints [26]. The same study associated the increase in SNS activity and effort perception with low glycogen stores [26]. In addition, researchers found that both young (aged: 19 years) and older participants (aged: 72 years) experienced a significant decrease in SDNN and total power (associated with ANS balance), due to the ingestion of a great amount of trans-fatty acids over five years [44]. In contrast, healthy young males showed a significant increase in the parasympathetic nervous system (PNS)-related HRV parameter, namely very-LF power as a percentage, due to the intake of a high-fat diet (70% of total energy from fat) [37]. The latter are similar to the results of our study, which also found that the intake of trans-fatty acids was positively related to HRR, which serves as an indicator of PNS activity. Lastly, since high-fat diets normally contain a great amount of saturated fats that

may cause insulin resistance and a reduction in blood flow, the above-mentioned are all factors that may cause an increase in PNS activity [39].

The current study also showed that the intake of micronutrients influences HRR during different match periods more than the intake of macronutrients. As mentioned, vitamin D was identified as the primary micronutrient to influence HRR. Furthermore, the results revealed that this particular vitamin was the only micronutrient to exert a significant, positive influence on the in-match HRR of players. Consequently, players who ingested an increased amount of vitamin D, experienced an increase in PNS activity. Similar results were reported by Dogdus et al. [18] who observed a significant increase in PNS activity after the ingestion of vitamin D in healthy males. The possible mechanism for the increase in PNS activity with the consumption of vitamin D, is that activated vitamin D binds directly to the nuclear receptors of the adrenergic neurons in the spinal cord and brain tissue, which results in an increase in PNS activity [45]. In addition, scientific evidence suggests that vitamin D is involved with the effective functioning of the cardiovascular system through the autocrine pathway [15]. The autocrine pathway is responsible for regulating the transfer of glucose to the brain and plays a crucial role in signalling processes and cell functioning [9, 15].

According to our study, the intake of calcium, another important micronutrient was significantly and negatively related to changes in the HRR-related parameters during the in-match period. This supports earlier research indicating that calcium and magnesium influenced SNS activity by facilitating insulin resistance [28]. Both, insulin resistance and insulin secretion rely on calcium homeostasis, whereas insulin functioning through the metabolic and pathophysiological pathways are influenced by serum calcium levels [55]. In this regard, the alteration in calcium levels may affect insulin secretion, since the release of voltage-operated calcium will initiate insulin exocytosis from β -cells, which leads to an increase in SNS activity [55]. Our research further showed that potassium had the second-largest negative correlation with the in-match HRR-related variables of participants, which suggests that increased potassium intake influenced HRR values negatively. Other research reported that higher potassium levels led to lowered pacemaker depolarisation rates in mice, with a consequent increase in maximum diastolic potential, which caused a decrease in HR [3]. Furthermore, researchers also regard potassium to be an important mineral for regulating the fluid, acid, and electrolyte balance of the body, as well as normal cell functioning [1]. The last-mentioned findings may explain why potassium had such a large influence on HRR during match periods in our particular study. However, the finding that

potassium intake had a negative influence on in-match HRR is in contrast with what previous researchers found. Previous researchers focused on participants of various ages (5-17 years), gender groups (women), and investigated the possible influence of potassium on cardiac autonomic control during non-competitive environments [1]. These are all factors that may have led to differences in HRR responses to the intake of potassium.

An unexpected finding of this study is that players showed below-average in- (12.78 ± 4.73) and post-match HRR values (14.34 ± 6.16) when compared to the reported average value of 38% for trained athletes [27]. A fast decrease in HR during short rest periods (60 sec) is caused by activation of the PNS, leading to rapid changes in maximal left ventricular function with a greater ejection fraction and myocardial contractility [42]. Such a fast decrease in HR after exercise will prevent excessive cardiac work, allowing players to better cope with high-intensity exercise and the demands of match play [40]. Therefore, the lower-than-expected HRR values may be an indication of a delayed parasympathetic reactivation during rest periods [8, 13]. Nevertheless, the high levels of pressure associated with real-life competitions will automatically result in sympathetic predominance and influence changes in ANS control, which, in turn, may give rise to different HRR values compared to values of trained athletes evaluated in laboratory-based settings.

Only one canonical correlation analysis delivered a strong significant correlation between the two sets of variables (micronutrients and HRR-related variables). However, a non-significant value was observed for the relationship between the macronutrients and HRR for the different match periods. Thus, despite a higher percentage of variance in the in- and post-match HRR parameters that could be explained by the macronutrient- (62.46%), compared to the micronutrient-related variables (58.17%), the results in Table 2 show that available CHO, which was the primary macronutrient to determine the canonical correlation coefficient, obtained a very high standard deviation. Therefore, values for this macronutrient-related variable varied a great deal from one individual to the next. The fact that canonical correlation analysis does not make strong normality assumptions means that outliers may cause non-significant results [38].

In conclusion, this study revealed that CHO availability, total sugars, added sugars, and trans-fatty acids were the macronutrients that exerted the greatest influence on changes in HRR-related variables over the different match periods. Available CHO had the biggest negative influence, while trans-fatty acids had the biggest positive influence on HRR. Consequently, the hypothesis that a 24-hour low-CHO diet would lead to significantly higher in- and post-match HRR values

than a high-CHO diet, of badminton players specifically, was rejected. The results also reveal that vitamin D is the micronutrient with the greatest positive influence on HRR, in comparison to calcium and potassium, which were identified as the primary micronutrients to negatively influence the HRR-related variables. As a result, the hypothesis that a 24-hour diet intake containing mineral- and vitamin-related components will lead to significantly higher in- and post-match HRR values of badminton players, was also rejected.

While all the hypotheses were rejected, it must be kept in mind that, until now, no available studies have investigated the influence of dietary intake on the parameters of HRR during different periods of a real-life badminton competition. Subsequently, our results suggest that HRR could potentially be used to determine whether athletes follow an optimal diet to maintain their most ideal autonomic state for competition participation. In light of this, the findings of this study are unique and will provide insight into an area of research where uncertainty remains. Nevertheless, since the relationships between different sets of variables were only determined for male badminton players from Africa researchers will not be able to generalise these results to all athletes. Consequently, future research should investigate the relationship between athletes' short-term diets and HRR through longitudinal studies for different populations. Results of the last-mentioned studies will allow researchers to gain a better understanding of the influence of athletes' short-term diets on ANS control during sport participation and training. In addition, while real-life studies provide information that better represent the aspects that sport-related professionals must deal with during their everyday lives, the randomisation of participants into control and experimental groups remains the most effective method to evaluate the possible influence of specific quantities of macro- and micronutrients on the different HRR parameters. However, time, and logistical constraints, as well as the unwillingness of players to change their diets during in-competition periods, make the implementation of the recommended methodology difficult.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest

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CHAPTER 5: SUMMARY, CONCLUSIONS, LIMITATIONS, AND RECOMMENDATIONS

5.1 SUMMARY

A need exists to evaluate the influence of a short-term diet on the heart rate variability (HRV) and heart rate recovery (HRR) values of sports participants. The knowledge that is gleaned, may provide researchers with a better understanding of the possible influence of sport participants' short-term diets on the activation and control of the autonomic nervous system (ANS) during real-life sport and exercise participation. In view of this need, the objectives of this study were: firstly, to determine the relationships between a 24-hour diet and the pre-, in-, and post-match HRV of badminton players, and secondly, to determine the relationships between a 24-hour diet and the in- and post-match HRR of badminton players.

Chapter 1 provided a brief overview of the problem statement that formed part of the literature base for the research questions. This chapter also included the research objectives, related hypotheses and information concerning the structure of the dissertation.

Chapter 2 consisted of a literature review titled: "Relationships between diet and the autonomic markers of heart rate in participants". The objectives of this literature review were to: Firstly, discuss the functioning of the ANS and the physiological mechanisms that underlie cardiac control through the different branches of the ANS, and; secondly, indicate, define, and discuss the different parameters of HRV as well as the meaning of each; thirdly, indicate, define, and discuss HRR as an ANS-related parameter; fourthly, discuss the protocols used to measure and determine HRV and HRR; fifthly, discuss studies that investigated the use of HRV and HRR in exercise and sport settings; sixthly, highlight the possible influence of 24-hour (short-term) diet on HRV and HRR during sport participation; seventhly, discuss the protocols and questionnaires that are used to determine short-term diet. Finally, indicate and discuss the limitations of current research investigating the use of HRV and HRR in an exercise or sport setting as well as research that focused on the influence of short-term diet on HRV and/or HRR.

Therefore, the chapter started by accentuating the vital role that the ANS plays in the functioning and control of the cardiac system during sport and exercise participation. Firstly, the ANS forms part of the central nervous system, which is responsible for regulating a large number of visceral bodily functions and processes. Furthermore, the functions of the ANS are executed via two

branches, namely the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS). The SNS is associated with the fight-or-flight response and prepares the body for stressful situations, whereas the PNS is associated with the rest and digest response, which is more dominant during resting situations. Reactivation of the PNS is impaired during high-intensity exercise, whereas SNS activation is stimulated during these conditions. Both these branches of the ANS innervate the heart and regulate the heart rate (HR). In this regard, the PNS causes bradycardia and decreases HR through the release of acetylcholine, while the SNS increases the depolarisation and myocardial contractility of the heart through the sympathetic cardio-accelerator nerves that release neuro-hormones, such as epinephrine and norepinephrine.

One of the indicators of ANS activation, namely HRV, is defined as the variation in time between consecutive beat-to-beat intervals when a certain period between each cardiac cycle elapses. Heart rate variability (HRV) is measured by calculating the variation in time between consecutive beat-to-beat intervals. Heart rate variability (HRV) data is obtained by making use of electrocardiogram (ECG) signals, wristwatch monitors (Polar, Suunto, and Apple) and portable devices. After the collection of HRV data, values are analysed by using HRV software packages. The derived variables are then categorised into time, frequency, and non-linear HRV parameters. The three categories of HRV-derived parameters are separately linked to the PNS and SNS branches of the ANS. The time-domain parameters include the mean of R-R intervals in milliseconds (Mean R-R), 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 percentage of consecutive N-N intervals that differ by more than 50 milliseconds (pNN50). The frequency-domain parameters consist of very low band frequencies (VLF), low band frequencies (LF), high band frequencies (HF), the ratio between LF and HF (LF/HF ratio), and total power. The final category of parameters is the non-linear components, which include the standard deviation 1 (SD1) and standard deviation 2 (SD2), and the ratio between SD1 and SD2. The natural logarithmic of the square root of the mean squared differences between successive R-R intervals in milliseconds (Ln-RMSSD) is regarded to be the most accurate HRV-related parameter, especially over shorter measurement periods. The HRV-related parameters, of which distributions are skewed, are usually presented in their natural logarithmic forms in order to lessen the variations in HRV-related parameter standards. Overall, researchers consider the above-mentioned time, frequency, and non-linear parameters of HRV to be valid and reliable measures for the evaluation of ANS activation in sport and exercise settings.

Another indicator of ANS activity, namely HRR, is determined by the coordinated interaction between parasympathetic reactivation and sympathetic withdrawal after sport and exercise participation. The main mechanism that underlies the exponential cardio-deceleration after exercise, is parasympathetic reactivation, and sympathetic withdrawal. These last-mentioned variables are measured by considering the absolute (bpm) or relative decrease in HR (in percentage) over a certain time after moderate to high-intensity exercise. Various researchers and practitioners prefer to evaluate and obtain athletes' HRR measures to monitor and determine their particular training responses, aerobic fitness levels, functional adaptations, recovery statuses, as well as participation levels. However, while both HRV and HRR measures are used to evaluate the ANS function, several researchers found no relationship between HRV and HRR. Their consequent findings indicate that the latter variables are independently linked to the ANS and, therefore, must be investigated separately.

The Polar, Suunto, and Apple HR monitors are regarded as well-established, valid, user-friendly, and affordable measuring devices for obtaining accurate and time-efficient HRV and HRR-related parameters in sport and exercise settings. For instance, researchers found that time (mean R-R, SDNN, RMSSD, and pNN50) and frequency-domain HRV measurements (VLF, LF, and HF) did not differ significantly between a Polar S810 HR-monitor and an ambulatory Holter ECG recorder. Consequently, absolute, and relative HRR values of sport participants can be successfully evaluated by using the last-mentioned type of HR monitors as they provide accurate HR measurements over short (60-seconds) and longer-term periods (30-minutes). Overall, researchers promote the use of these specific HR devices to successfully monitor ANS control through HRV and HRR and evaluate athletes in their competitive and training environments. However, the reliability of the aforementioned devices for use in sport and exercise settings has not yet been proven. Therefore, future researchers must assess available HR monitors, to confirm the reliability for use in sport and exercise settings.

Various researchers have investigated the HRV of participants in sport and exercise-related settings and confirmed that researchers and coaches can use HRV measures to monitor and detect early signs of overloading. These measures can also be used to indicate and monitor the possible influence of pre-competition stressors on the ANS of sport participants. Furthermore, researchers that have investigated the HRV of team-sport participants found that weekly changes in HRV were strongly associated with adaptations in participants' aerobic capacity, as measured by maximal oxygen consumption ($\dot{V}O_{2max}$). The latter result was further confirmed by researchers who

observed that endurance-trained athletes displayed higher HRV values than non-endurance trained participants and that these values were significantly associated with aerobic fitness levels. Therefore, HRV allows researchers and coaches to monitor athletes' overall training status, as well as stress and overload, especially during competition periods.

On the other hand, researchers also found that HRR, which was measured for 60 seconds, can be used as an indicator of training status. For example, highly trained athletes showed significantly faster HRR values compared to moderately trained athletes. Furthermore, researchers concluded that athletes with higher aerobic fitness levels who compete at a higher level recover faster after sport-specific exercise, as indicated by their better HRR profiles. Some researchers also found that the HRR of endurance athletes can be used as an indicator of recovery. Therefore, the HRR of athletes can be used to monitor the training responses, aerobic fitness, and recovery status of sport participants.

While HRV- and HRR-related parameters are valuable measures to evaluate and monitor participants' ANS responses during exercise and sport participation, only a small number of researchers have investigated the possible influence of confounding variables such as short-term diet on the control of the ANS in participants. Researchers who investigated the influence of dietary components on the ANS control of participants found that a low-carbohydrate (CHO) diet led to significant increases in the low-frequency relative power expressed as normalised units (LFnu) during the execution of a cycling test. A different study revealed that the ingestion of a high-fat diet by participants led to a significant increase in the VLF power. In addition, researchers indicated that certain vitamins and minerals may also influence the ANS control. In this regard, the intake of vitamin D by participants led to an increase in parasympathetic activity, whereas the intake of calcium and magnesium caused significantly higher SNS responses. Such studies confirm the possible influence of a short-term diet on the ANS response of participants.

Researchers that conduct diet-based studies make use of different subjective dietary assessment methods to collect the dietary intakes of participants. These include the 24-hour dietary recall questionnaire (24-hDRQ), dietary records (DR), dietary history assessments (DHA), and the food frequency questionnaire (FFQ), all of which make use of open- and/or closed-ended questionnaires. However, the validity and reliability of these dietary instruments for use in sport and exercise settings must still be proven. Nonetheless, the immediacy of the 24-hDRQ enables participants to recall most of their dietary intake, which makes it more accurate than other

measuring instruments. The 24-hDRQ is also regarded to be the least biased self-report instrument, and, therefore, useful for most research purposes. Nevertheless, more recently, researchers have found that the peri-training nutrition (PTN) approach can be used to effectively monitor the habitual dietary practices of athletes to determine pre-, in, and post-training energy and nutrient intakes. Therefore, the PTN approach allows researchers to collect more accurate readings when evaluating the dietary profiles of sports participants.

Considering the fact that changes in the short-term diet content of, in particular, carbohydrates (CHO), minerals, and vitamins have a significant influence on participants' SNS and PNS activation, there is an urgent need for studies of this nature. Despite scientific proof of the influence of short-term diets on ANS control, no studies have thus far investigated this influence during real-life competitions. Until now, researchers have investigated the influence of diet on ANS control through laboratory-based protocols instead of actual competitions. In contrast to laboratory-based protocols, real-life competitions bring about high-pressure situations, which cause sympathetic dominance and changes in ANS control. Therefore, laboratory-based protocols may not provide an accurate picture of athletes' ANS profile changes during real-life competitions. Consequently, future research should investigate the relationship between different populations of athletes' short-term diets and ANS control during real-life competitions. This will allow researchers to gain a better understanding of the influence of athletes' short-term diets on ANS control during sport participation and training. Additionally, the evaluation of the ANS could potentially be used to determine whether athletes follow an optimal diet to maintain their most ideal autonomic state for competition participation.

Chapter 3 consisted of the first article, which was compiled according to the guidelines of the *Journal of Strength and Conditioning Research*, titled: Relationships between 24-hour diet and pre-, in-, and post-match HRV of badminton players. In particular, it aimed to determine the relationships between a 24-hour diet and the pre-, in-, and post-match HRV of badminton players. The article succeeded in showing that all canonical correlations for the relationships between the macronutrient, micronutrient, and HRV parameters over different match periods, were significant ($p = 0.0000-0.03$). The only exception was the canonical correlation ($R_c = 0.97, p = 0.105$) between the 24-hour in-competition macronutrient intake and the post-match HRV-related variables of the badminton players. Overall, canonical functions accounted for between 80.44% and 98.01% of the total variation between the two canonical roots. Furthermore, trans-fatty acids and available carbohydrates were the macronutrients with the biggest influences on changes in HRV parameters,

such as very low band peak frequencies in hertz (Peak VLF Hz) during the pre-match period. The HRV parameter that was mostly influenced by the last-mentioned macronutrients during the in- and post-match periods was the natural logarithmic transformation of the square root of the mean squared differences between successive R-R intervals in milliseconds $\text{Ln-RMSSD (ms}^{-1}\text{)}$ during the. Results further revealed that calcium (during the pre- and in-match periods) and potassium (during the post-match period) were the micronutrients that contributed most meaningfully to the changes in HRV parameters ($\text{Ln-RMSSD (ms}^{-1}\text{)}$, Peak VLF Hz and Mean R-R ($\text{ms}^{-1}\text{)})$ during different periods of match-play.

Chapter 4 consisted of the second article, which was compiled according to the guidelines of the *International Journal of Sports Medicine*, and titled: Relationships between 24-hour diet and the in- and post-match heart rate recovery of badminton players. Its purpose was to determine the relationships between the 24-hour diet and the in- and post-match HRR of badminton players. The results revealed that canonical correlations for the relationships between the 24-hour diet-related components and the in- and post-match HRR-related variables obtained correlation values of $R = 0.84$ ($p = 0.10$) for the macronutrient components and $R = 0.92$ ($p = 0.03$) for the micronutrient components. The first canonical correlation analysis revealed a strong non-significant correlation, while the second canonical correlation analysis revealed a strong significant canonical correlation. Consequently, canonical functions accounted for between 70.56%, and 84.64% of the total variation between the two canonical roots. Furthermore, the macronutrients with the greatest influence on changes in HRR-related variables over the two match periods were carbohydrate availability, total sugars, added sugars, and trans-fatty acids. Results also revealed that vitamin D, calcium, and potassium were the micronutrients that had the biggest influence on changes in HRR-related variables of participants over the two match periods.

5.2 CONCLUSIONS

The study's conclusions are presented according to the set hypotheses that were presented in Chapter 1.

Hypothesis 1: *A 24-hour low CHO diet will lead to significantly higher SNS-related pre-, in-, and post-match HRV (very low band peak frequencies in hertz (Peak VLF Hz), VLF relative power expressed as a percentage (VLF%), low band peak frequencies in hertz (Peak LF Hz), LF relative power expressed as a percentage (LF%), and the natural logarithmic transformation of the standard deviation 2 (Ln-SD2)) values of badminton players compared to a high-CHO diet.*

Furthermore, a 24-hour low-CHO diet will lead to significantly lower PNS-related pre-, in-, and post-match HRV (high band peak frequencies in hertz (Peak HF Hz), HF relative power expressed as a percentage (HF%), the natural logarithmic transformation of HF relative power expressed as normalised units (Ln-HFnu), SDNN, the natural logarithmic transformation (Ln) of RMSSD, and the mean of R-R intervals in milliseconds (Mean R-R) and SD1) values of badminton players compared to a high-CHO diet. Subsequently, this specific hypothesis was rejected based on the findings that although all the canonical correlation analyses revealed strong correlations, the canonical correlation between the 24-hour, in-competition macronutrient intake and the post-match HRV-related variables of badminton players was non-significant. Furthermore, trans-fatty acids, not available CHO were the macronutrient that had the biggest influence on changes in HRV parameters over the different match periods. In addition, there was no clear distinction between the direction of the influence of CHO and fat on the activation of the SNS and PNS over different match periods since PNS and SNS-related HRV parameters were either negatively or positively influenced by the intake of these macronutrients.

Hypothesis 2: *A 24-hour diet that contains less mineral- and vitamin-related components will lead to significantly higher SNS-related pre-, in-, and post-match HRV (Peak VLF Hz, VLF%, Peak LF Hz, LF%, and Ln-SD2) values of badminton players than a diet containing more mineral and vitamin-related components. Furthermore, a 24-hour diet with less mineral and vitamin-related components will lead to significantly lower PNS-related pre-, in-, and post-match HRV (Peak HF Hz, HF%, Ln-HFnu, SDNN, Ln-RMSSD, Mean R-R, and SD1) values of badminton players than a diet that contains more mineral and vitamin-related components.* Hypothesis 2 was also rejected since the results showed that there was no clear distinction between the direction of the influence of the different micronutrients on the activation of the SNS and PNS over different match periods. The PNS and SNS-related HRV parameters were either negatively or positively influenced by the intake of different micronutrients. However, the canonical correlations for the relationships between the 24-hour micronutrient intake and the competition-related HRV parameters over the different match periods were significant. The micronutrient that contributed the most to pre-and in-match HRV changes, was calcium. Potassium was distinguished as the primary micronutrient to influence post-match HRV changes.

Hypothesis 3: *A 24-hour low-CHO diet will lead to significantly lower HRR values of badminton players compared to a high-CHO diet.* Hypothesis 3 is rejected since the canonical correlation analysis of the relationship between the 24-hour diet-related macronutrient components and the

in- and post-match HRR-related variables revealed a strong non-significant *correlation*. In addition, further analyses revealed that an increase in participants' consumption of available CHO, total sugars, and added sugars influenced both their, in-, and post-match HRR values negatively. The latter also identified available CHO and total sugars as the macronutrients with the greatest influence on HRR, during both match periods.

Hypothesis 4: *A 24-hour diet that contains more mineral- and vitamin-related components will lead to significantly higher in- and post-match HRR values of badminton players than a diet containing less mineral and vitamin-related components.* Although the canonical correlation analysis revealed a strong significant correlation of 0.92 ($p = 0.03$) between participants' micronutrient intake and their related in and post-match HRR-related variables, there was an increase in their consumption of calcium and potassium had a negative influence on their HRR. On the other hand, vitamin D had a positive influence. Moreover, the latter was identified as having the greatest influence on participants' HRR during the two match periods, in comparison to other micronutrients. In view of these results, Hypothesis 4 was rejected.

Overall, the above-mentioned findings suggest that trans-fatty acids were the macronutrient that had the biggest influence on changes in HRV parameters over the different match periods. This was followed by available CHO that had the second biggest influence during the three match periods. Added sugars were identified as the third most influential macronutrient in terms of both the in- and post-match periods, whereas total sugars served as the third most contributing macronutrient to pre-match HRV changes. Nevertheless, our particular study did not provide a clear distinction between the possible influence of CHO and fat on the activation of the SNS and PNS over different match periods of badminton players.

The micronutrient that contributed the most to pre and in-match HRV changes, was calcium. Potassium was distinguished as the primary micronutrient to influence post-match HRV changes. Our results further indicated that vitamin D, together with boron, contributed to changes in the HRV-related parameters during the pre-match period. However, none of these micronutrients was identified as being major contributors to changes in HRV during the in- and post-match periods. Again, there was no clear distinction between the direction of the influence of the different micronutrients on the activation of the SNS and PNS over different match periods, as PNS and SNS-related HRV parameters were either negatively or positively influenced by their ingestion.

Nevertheless, findings showed that the intake of micronutrients influenced HRV more during different match periods than the intake of macronutrients.

The HRR-related analyses revealed that an increase in participants' consumption of available CHO, total sugars, and added sugars influenced both their, in, and post-match HRR values negatively. The latter, namely added sugars, also identified available CHO and total sugars as the macronutrients with the greatest influence on HRR during both aforementioned match periods. In contrast to this, the consumption of trans-fatty acids had a positive influence on these variables. In terms of the relevant micronutrients, an increase in participants' consumption of calcium and potassium, in particular, had a negative influence on their HRR, whereas vitamin D exerted a positive influence. Moreover, the latter was identified as having the greatest influence on participants' HRR during the two match periods, in comparison to other micronutrients.

Given the above-mentioned results, sport scientists should ensure that sport participants' short-term, in-competition diets especially include trans-fatty acids, CHO, added sugars, total sugars, calcium, and potassium since these components meaningfully influenced changes in ANS-related parameters over different periods of a real-life badminton match. In addition, the match period-specific influences suggest that sport-related professionals should ensure that players ingest enough vitamin D and boron before the start of a match since these micronutrients exerted their ANS influence, especially during this period.

5.3 LIMITATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCHERS

To the researchers' knowledge, this is the first study of its kind to investigate the effects of dietary intake on the parameters of HRV and HRR during different periods of a real-life badminton competition. While all the hypotheses in this study were rejected, the significance of several correlation coefficients suggests that HRV and HRR could potentially be used to determine whether athletes follow an optimal diet to maintain their most ideal autonomic state for competition participation. Furthermore, the uncertainty concerning the direction of the macro- and micronutrients' influences on the activation of the SNS and PNS is something that needs to be addressed. Nevertheless, since previous research did not investigate the effects of dietary intake on the parameters of HRV and HRR during different periods of a real-life badminton competition, the findings of this study provide necessary insight into an area of research where uncertainty remains. Nonetheless, the various limitations of this study, together with possible

recommendations should be considered by future researchers who wish to focus on this field of study. Herewith a summary of the limitations and recommendations of this study:

- **Limitation:** The relationships between different sets of variables were only determined for African, male badminton players, which means that researchers will not be able to generalise these study results to all groups of athletes.
- **Recommendation:** Although studies of specifically defined groups allow researchers to develop their knowledge concerning a certain research theme, the strength and nature of the relationships between short-term diet parameters of ANS function should be evaluated and measured through longitudinal studies among different populations of athletes.
- **Limitation:** The possible influence of badminton players' short-term diets on their ANS control was investigated by correlating their habitual short-term, in-competition diets to their actual, real-life competition HRV and HRR values.
- **Recommendation:** While real-life studies provide information that better represent the aspects that sport-related professionals deal with during their everyday lives, the randomisation of participants into control and experimental groups remains the most effective method to evaluate the possible influence of specific quantities of macro- and micronutrients on the various ANS-related parameters.
- **Limitation:** Researchers measured participants' ANS-related parameters during different periods over two to three matches (short-term). Furthermore, dietary intakes were only determined over one interview session. More accurate ANS and in-competition dietary profiles of participants will be obtained by monitoring HRV, HRR, and dietary intakes over a longer period.
- **Recommendation:** Therefore, future researchers should use a minimum of five to seven measurement days for the determination of participants' HRV and HRR profiles. It would also be advisable to collect dietary data more frequently so that the accuracy of in-competition dietary profiles can be verified.
- **Limitation:** Although the intake of different dietary components may influence the ANS profile of sport participants, other factors may also influence their in-competition ANS profiles. These include factors such as recovery indicators (sleep duration and quality, mood, hydration levels, etc.) and their initial fitness levels.
- **Recommendation:** Future researchers should keep in mind the above-mentioned factors when investigating the possible influence of dietary intake on the ANS profile of sport participants.

- **Limitation:** Even though a log transformation was used to improve the normality of HRV data, the canonical correlation analysis method that was used in this study does not make strong normality assumptions; this means that outliers may have caused non-significant results.
- **Recommendation:** Therefore, future researchers should also consider other statistical analysis methods to improve the accuracy and interpretability of study results.
- **Limitation:** Although the 24-hDRQ is, to date, regarded to be the most meticulous and comprehensive dietary approach, researchers recommend the combined use of various dietary methods to increase the accuracy of dietary data.
- **Recommendation:** The more recent introduction of the peri-training nutrition (PTN) approach may allow researchers and practitioners to monitor the habitual dietary practices of athletes, more accurately and effectively. Therefore, future researchers should make use of this approach to collect the dietary data of sport participants.

However, time and logistical constraints, as well as the unwillingness of players to change their diets during in-competition periods, may make the implementation of certain recommendations difficult.

APPENDIX A: ETHICAL APPROVAL FOR UMBRELLA PROJECT



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Ethics Committee
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ETHICS APPROVAL OF PROJECT

The North-West University Research Ethics Regulatory Committee (NWU-RERC) hereby approves your project as indicated below. This implies that the NWU-RERC grants its permission that provided the special conditions specified below are met and pending any other authorisation that may be necessary, the project may be initiated, using the ethics number below.

Project title: HEART RATE VARIABILITY AND RECOVERY AS WELL AS GPS MATCH ANALYSIS CHARACTERISTICS IN RELATION TO MATCH RESULTS IN AFRICAN MALE BADMINTON PLAYERS																																											
Project Leader: Prof B Coetzee																																											
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Approval date: 2015-04-01	Expiry date: 2016-12-16																																										

Special conditions of the approval (if any): (none)

General conditions:

While this ethics approval is subject to all declarations, undertakings and agreements incorporated and signed in the application form, please note the following:

- The project leader (principle investigator) must report in the prescribed format to the NWU-RERC:
 - annually (or as otherwise requested) on the progress of the project,
 - without any delay in case of any adverse event (or any matter that interrupts sound ethical principles) during the course of the project.
- The approval applies strictly to the protocol as stipulated in the application form. Would any changes to the protocol be deemed necessary during the course of the project, the project leader must apply for approval of these changes at the NWU-RERC. Would there be deviation from the project protocol without the necessary approval of such changes, the ethics approval is immediately and automatically forfeited.
- The date of approval indicates the first date that the project may be started. Would the project have to continue after the expiry date, a new application must be made to the NWU-RERC and new approval received before or on the expiry date.
- In the interest of ethical responsibility the NWU-RERC retains the right to:
 - request access to any information or data at any time during the course or after completion of the project;
 - withdraw or postpone approval if:
 - any unethical principles or practices of the project are revealed or suspected,
 - it becomes apparent that any relevant information was withheld from the NWU-RERC or that information has been false or misrepresented,
 - the required annual report and reporting of adverse events was not done timely and accurately,
 - new institutional rules, national legislation or international conventions deem it necessary.

The Ethics Committee would like to remain at your service as scientist and researcher, and wishes you well with your project. Please do not hesitate to contact the Ethics Committee for any further enquiries or requests for assistance.

Yours sincerely

Linda du Plessis

Prof Linda du Plessis
Chair NWU Research Ethics Regulatory Committee (RERC)

Digitally signed by Linda du Plessis
DN: cn=Linda du Plessis, o=NWU,
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APPENDIX B: ETHICAL APPROVAL FOR THE SUB-STUDY



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studies)

29 August 2019

ETHICS APPROVAL LETTER OF STUDY

Based on approval by the North-West University Health Research Ethics Committee (NWU-HREC) on 20/08/2019, the NWU-HREC hereby approves your study as indicated below. This implies that the NWU-HREC grants its permission that, provided the general conditions specified below are met and pending any other authorisation that may be necessary, the study may be initiated, using the ethics number below.

Study title: Relationships between 24-hour diet and autonomic markers of heart rate in badminton players																	
Principal Investigator/Study Supervisor/Researcher: Prof B Coetzee																	
Student: P Bonthuys-24003247																	
Ethics number:																	
N	W	U	-	0	0	1	9	9	-	1	4	-	A	1	-	0	4
Institution			Study Number					Year		Status		Sub-study					
<i>Status: S = Submission; R = Re-Submission; P = Provisional Authorisation; A = Authorisation</i>																	
Application Type: Sub-study															Risk:		
Commencement date: 29/08/2019															Minimal		
Expiry date: 31/08/2020																	
Approval of the study is provided for a year, after which continuation of the study is dependent on receipt and review of an annual monitoring report and the concomitant issuing of a letter of continuation. A monitoring report is due at the end of August annually until completion.																	

General conditions:

While this ethics approval is subject to all declarations, undertakings and agreements incorporated and signed in the application form, the following general terms and conditions will apply:

- The principal investigator/study supervisor/researcher must report in the prescribed format to the NWU-HREC:
 - Annually on the monitoring of the study, whereby a letter of continuation will be provided annually, and upon completion of the study; and
 - without any delay in case of any adverse event or incident (or any matter that interrupts sound ethical principles) during the course of the study.
- The approval applies strictly to the proposal as stipulated in the application form. Should any amendments to the proposal be deemed necessary during the course of the study, the principal investigator/study supervisor/researcher must apply for approval of these amendments at the NWU-HREC, prior to implementation. Should there be any deviations from the study proposal without the necessary approval of such amendments, the ethics approval is immediately and automatically forfeited.
- Annually a number of studies may be randomly selected for active monitoring.
- The date of approval indicates the first date that the study may be started.
- In the interest of ethical responsibility, the NWU-HREC reserves the right to:

- request access to any information or data at any time during the course or after completion of the study;
- to ask further questions, seek additional information, require further modification or monitor the conduct of your research or the informed consent process;
- withdraw or postpone approval if:
 - any unethical principles or practices of the study are revealed or suspected;
 - it becomes apparent that any relevant information was withheld from the NWU-HREC or that information has been false or misrepresented;
 - submission of the annual monitoring report, the required amendments, or reporting of adverse events or incidents was not done in a timely manner and accurately; and/or
 - new institutional rules, national legislation or international conventions deem it necessary.
- NWU-HREC can be contacted for further information via Ethics-HRECApply@nwu.ac.za or 018 299 1206

The NWU-HREC would like to remain at your service and wishes you well with your study. Please do not hesitate to contact the NWU-HREC for any further enquiries or requests for assistance.

Yours sincerely,



Digitally signed by Wayne
Towers
Date: 2019.08.29
16:26:41 +02'00'

Prof Wayne Towers
Chairperson NWU-HREC



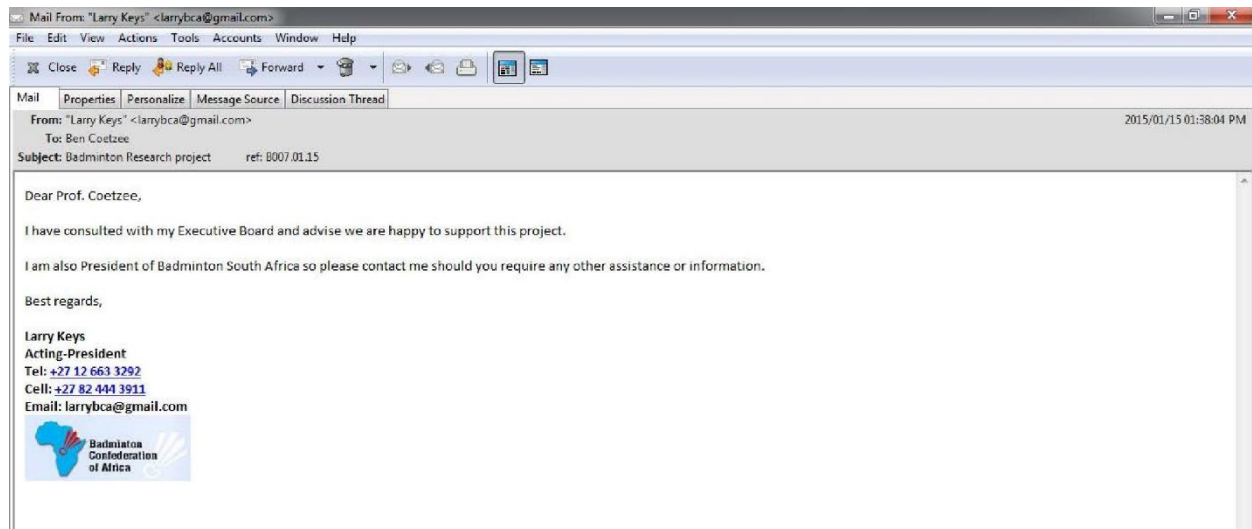
Digitally signed
by Prof Minnie
Greeff
Date: 2019.08.30
06:56:03 +02'00'

Prof Minnie Greeff
Head of the Faculty of Health Sciences Ethics Office

Current details (23239522) G:\My Drive\0. Research and Postgraduate Education\0.1.5.4 Templates\0.1.5.4.2_NWU-HREC_EAL.docm
20 August 2019

File Reference: 9.1.5.4.2

APPENDIX C: PERMISSION LETTER FROM BADMINTON CONFEDERATION OF AFRICA



APPENDIX D: PERMISSION LETTER FROM BADMINTON SOUTH-AFRICA

Page 1 of 1

Ben Coetzee - Research Project Badminton

From: "Klaas Visser" <landas@lando.co.za>
To: "Ben Coetzee NWC" <Ben.Coetzee@nwu.ac.za>
Date: 2014/04/08 09:06 AM
Subject: Research Project Badminton
CC: <stewartjcarson@gmail.com>, "Badminton SA" <badmintonsa@nwu.ac.za>

Dear Ben

We have discussed your proposal at our recent Board meeting and would like to become involved in your research project. We can clearly see the advantages for Badminton South Africa

How do you suggest we go about it? We are planning a training camp in Benoni from 20 to 22 April (prior to participating in the All Africa Badminton Championships in Lobatse, Botswana) All our National Players will be present. Perhaps it is the ideal situation to discuss this with the players. Or would you rather focus on our top u/19 players? They are currently in Malaysia participating in the World Junior Championships. The SA under 19 tournament is scheduled for Bloemfontein the 1st week of the schools holiday as another option

Our National Head coach Stewart Carson will run the training camp in Benoni

In future please direct all correspondence pertaining to your research to me as the High Performance Manager

Your research will play a vital role in updating and our "Badminton For Life" Long Term Participant Development Plan document, I will ask Stewart to give you a copy, otherwise I can sent it to you via Dropbox

Kind regards,

Klaas Visser
High Performance Manager
Chair Schools and Junior Section
Vice-President Administration

BADMINTON SOUTH AFRICA

Website: www.badmintonso.org
Email: landas@lando.co.za
admin@stickbond.co.za

Tel: [+27 28 271 5321](tel:+27282715321)
Fax: [+27 28 271 5521](tel:+27282715521)
Mobile: [+27 82 878 4566](tel:+27828784566)

file:///C:/Users/10090053/AppData/Local/Temp/XTgrpwisw/5343BC24PC/KD1PCM1 .. 2014/10/17

APPENDIX E: PERMISSION LETTER FROM BADMINTON WORLD FEDERATION

BADMINTON WORLD FEDERATION



12.02.2014

Dear Ben

Thank you for your time during my recent visit to RSA. I was interested to discuss the Badminton research proposal you are currently developing concerning African player characteristics.

Badminton is a sport which is certainly under researched in Africa, with very little specific information available. BWF are therefore happy to confirm its support for this project and I look forward to seeing the outcomes.

If you require further assistance in terms of contacts or recommendations please do not hesitate to contact me.

Kind regards

A handwritten signature in black ink, appearing to read 'Ian Wright'.

Ian Wright

Director of Development

Badminton World Federation

Unit 17.05, Level 17, Amoda Building
22 Jalan Imbi
55100 Kuala Lumpur
Malaysia

T +603 2141 7155
F +603 2143 7155
E bwf@bwfbadminton.org
W www.bwfbadminton.org

APPENDIX F: PERMISSION LETTER FROM BOTSWANA BADMINTON ASSOCIATION



P O Box 201369
Gaborone
Botswana
Telefax
Email: info@botswanabadminton.com

24th February 2015

Prof. Ben Coetzee
Private Bag X6001
Potchefstroom
South Africa 2520

RE: RESEARCH PROPOSAL SUBMITTED TO BOTSWANA BADMINTON ASSOCIATION

The above subject matter refers.

The Executive Committee of the Botswana Badminton wishes to acknowledge receipt of your research proposal document and a confirmation letter from BWF dated 13th January 2015 and 12th February 2015 respectively.

In light of the above, we wish to confirm our agreement to grant you permission to conduct the research with our players, coaches and managers at your disposal.

Do not hesitate to contact the undersigned for more information.

Thank you.

Yours faithfully

Thuso Mudongo (Mr)

Secretary General

/For President

Mobile: (+267) 72151225 / 71661990 / 73399809

**Email: secretary@botswanabadminton.com
ttndongos@yahoo.co.uk**



APPENDIX G: PARTICIPATION LEAFLET AND CONSENT FORM FOR BADMINTON PLAYERS



NORTH-WEST UNIVERSITY
YUNIBESITHI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
POTCHEFSTROOM CAMPUS

APPROVED

HREC Stamp

PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM FOR BADMINTON PLAYERS WHO ARE PARTICIPATING IN THE BADMINTON STUDY.

TITLE OF THE RESEARCH PROJECT:

Heart rate variability and recovery as well as global positioning system (GPS) match analysis characteristics in relation to match results in African male badminton players

REFERENCE NUMBERS: NWU-0199-14-A1

PRINCIPAL INVESTIGATOR:

Prof. Ben Coetzee

ADDRESS:

Physical Activity, Sport and Recreation
Faculty of Health Sciences
Building K21
North-West University
Potchefstroom
2522

CONTACT NUMBER:

0182991803

You are being invited to take part in the **Badminton Analysis Project** that forms part of post graduate, PhD-studies. Please take some time to read the information presented here, which will explain the details of this project. Please ask the researcher any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research entails and how you could be involved. Also, your participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively

in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

This study has been approved by the **Health Research Ethics Committee of the Faculty of Health Sciences of the North-West University (NWU-0199-14-A1)** and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki and the ethical guidelines of the National Health Research Ethics Council. It might be necessary for the research ethics committee members or relevant authorities to inspect the research records.

What is this research study all about?

- *This study will be conducted at LC de Villiers indoor training centre at the University of Pretoria and the indoor sport centre of the Show Grounds in Pretoria and will involve the analysis of matches via heart rate, Global Positioning System and video monitoring. Researchers will also determine your mood states and recovery status as well as your habitual dietary intake by making use of questionnaires and an interview, respectively. Experienced sport science researchers trained in human movement and sport science as well as dietetics will conduct the analyses. The aim is to recruit between thirty and forty male players to participate in this study.*
- *The objectives of this research are to determine the meaningful changes in the way that the heart rate varies from one beat to the next (HRV) and the degree in which the heart rate recovers (HRR) during the course of a tournament as well as the relationships between these last-mentioned variables and match results in elite African badminton players. Furthermore, to determine the influence of elite African badminton players' pre-competition dietary preferences, hydration status, sleep quality and quantity as well as mood states on HRV and HRR during the course of a tournament. Lastly, the researchers are also going to determine the singles match characteristics of male badminton players who participated in National and/or International Championships.*

Why have you been invited to participate?

- *You have been invited to participate because you are a male singles badminton player who is participating in a National or International Championship.*
- *You have also complied with the following inclusion criteria: You provided voluntary consent, while your manager and coach gave permission for you to participate in the study.*
- *Furthermore, you are actively involved and competing as a member of your provincial or national team and you are totally free of any injuries as well as illnesses.*
- *You will be excluded if: you become injured or ill at any time or if you are not prepared to play a match while wearing a heart rate and global positioning system (GPS) monitor. Furthermore, you will also be excluded if you do not fill in the questionnaires or undertake a 30 min long interview. Also, players who do not want to be video recorded during match play will also be excluded from the study.*

What will your responsibilities be?

- *You will be expected to undergo body mass and stature measurements in the bath room of the venue where you are participating, fill in a demographic and*

general information as well as a general recovery and hydration status questionnaire and the Stellenbosch Mood Scale. You will also be expected to wear a GPS and heart rate monitor during all matches that you play so that you can be monitored during match play. Lastly, you will also be expected to undertake a 30 minute long interview about your habitual dietary preferences in a secluded room where your privacy will be assured.

Will you benefit from taking part in this research?

- Among the direct benefits are, that you as a player will be able to gain access to your results as well as a personalized report explaining the results. Your data will also be used to explain to you and/or your coach orally during the duration of the different tournaments how your conditioning programmes can be changed in such a way that it prepares you for the demands of match play. Players and coaches will also be afforded the opportunity to talk to the researchers about any conditioning advice that they have a need for. Furthermore, the heart rate, HRV and HRR data will allow the researchers to evaluate players' recovery and fitness levels which may assist you and your coach to identify weak points and to identify factors that are detrimental to your recovery. As part of the research project you will also be afforded the opportunity to do an interview through which your dietary preferences and profile will be determined and evaluated by a dietician. Data with regard to hydration levels, mood states and sleeping quality and quantity will also allow researchers to provide you with feedback concerning these aspects. An indirect benefit of the study is an expansion of existing expert knowledge in the field of Applied Sport Science which can be transferred to the wider sporting community.

Are there risks involved in your taking part in this research?

- Risks will be minimised and the researchers will aim to maximise potential benefits that are likely to have a valuable impact on you, either directly or indirectly. No severe physical, psychological, social stress or other negative consequences beyond the risks encountered in normal match play are foreseen in this study. Each player and coach will be responsible for the warm-up before each match to prepare you physically and physiologically for the demands of match play and to decrease injury risk. The Badminton World Federation requires that medical staff must be available at all times during the tournament, which means that a medical physician and physiotherapist will be available during the course of the tournament, should any injuries occur. In case of illness or injury you will immediately be withdrawn from the study and will be allowed to leave at any time if you feel so. You may experience a bit of discomfort due to the Polar Heart Rate Transmitter Belt that is tied around your chest and the GPS harness that is worn on your back during match play. However, the warm-up period will be used to adjust the heart rate transmitter belt and GPS harness according to your preference and to make you use to the equipment. If you do not feel comfortable to wear the equipment during match play, you will be allowed to play without the equipment.
- For some players it may be uncomfortable to fill in the Stellenbosch Mood Scale questionnaires a few minutes before the match as it may make them feel more anxious.

- Some players may find it uncomfortable to talk about their dietary patterns to the researcher while they are being recorded. However, the interviewer will set the interviewee at ease by providing you with a short introduction of what the interview is going to entail and also by allowing you to ask any questions that are related to concerns about the interview. The interviewer will maintain a demeanour of friendliness, openness and genuineness. Furthermore, the interview will be conducted in a comfortable, good sized, quiet and private meeting room. The interviewer will also make sure that his questions are clear, well-phrased and as jargon-free as possible to help avoid any confusion.

What will happen in the unlikely event of some form of discomfort occurring as a direct result of your taking part in this research study?

- Should you have the need for further discussions after match play an opportunity will be arranged for you to do so. The Badminton World Federation requires that medical staff must be available at all times during matches, which means that first aid personnel will be available for the duration of each match, should any injuries occur. In case of illness or injury you will immediately be withdrawn from the study and will be allowed to leave at any time if you feel so.

Who will have access to the data?

- Anonymity will be partial due to the fact that the coaches and managers also want the feedback of the match analyses but the researchers will respect the decision of each player in order to protect his anonymity. Data will be coded to ensure that no link can be made to a specific player. Confidentiality will be ensured by deleting audio records of interviews after data has been captured. Reporting of findings will be anonymous by only authorising the head researcher to have control over the distribution of these findings. Only the head researcher and research assistants will have access to the data and will also sign a confidentiality agreement to protect players. Data will be kept safe and secure by locking hard copies in locked cupboards in the researcher's office and for electronic data it will be password protected. Data will be stored for 7 years after which the information will be shredded and e-copies deleted.

What will happen with the data/samples?

- This is a once off collection and data will be kept at the North-West University and analysed at the North-West University.

Will you be paid to take part in this study and are there any costs involved?

- No, you will not be paid to take part in the study. There will also be no costs involved for you, if you do take part.

Is there anything else that you should know or do?

- You can contact Ben Coetzee at 018 2991803 if you have any further queries or encounter any problems.
- You can contact the Health Research Ethics Committee via Mrs Carolien van Zyl at 018 299 2089; carolien.vanzyl@nwu.ac.za if you have any concerns or complaints that have not been adequately addressed by the researcher.
- You will receive a copy of this information and consent form for your own records.

How will you know about the findings?

- The findings of the research will be shared with you if you are interested. You are welcome to contact us regarding the findings of the research. We will be sharing the findings with you as soon as it is available

Declaration by participant

By signing below, I agree to take part in a research study titled: **Badminton Analysis Project**

I declare that:

- I have read this information and consent form and it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions to both the person obtaining consent, as well as the researcher and all my questions have been adequately answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurised to take part.
- I may choose to leave the study at any time and will not be penalised or prejudiced in any way.
- I may be asked to leave the study before it has finished, if the researcher feels it is in my best interests, or if I do not follow the study plan, as agreed to.

Signed at (place) on (date) 20....

.....
Signature of participant

.....
Signature of witness

Declaration by person obtaining consent

I (name) declare that:

- I explained the information in this document to
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did/did not use an interpreter.

Signed at (place) on (date) 20....

.....
Signature of person obtaining consent

.....
Signature of witness

Declaration by researcher

I (name) declare that:

- I explained the information in this document to
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did/did not use an interpreter.

Signed at (place) on (date) 20....

.....
Signature of researcher

.....
Signature of witness

APPENDIX H: GENERAL INFORMATION AND DATA COLLECTION

QUESTIONNAIRES



*Physical Activity,
Sport & Recreation*

General Information Questionnaire and Test Protocol for the HRV badminton match analyses project

GENERAL INFORMATION

Please write clearly!

1. Geographical Information

2. Surname: Initials First Name

--	--	--

1.2 Age:

<u>Years:</u>	<u>Months:</u>
---------------	----------------

1.3 Birth date:

<u>Year:</u>	<u>Month:</u>	<u>Day:</u>
--------------	---------------	-------------

1.4 Permanent residential address:

1.5 Permanent postal address:

1.6 Phone numbers:

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

1.7 Country that you are presenting during this championship

--

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 badminton.

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

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

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

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

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

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

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

2.5 Frequency of training - how many days per week do you normally do training on the field or road?

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

2.6 How many hours per day do you normally train?

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

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

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

2.8 How many hours per day do you normally spend on training on the court?

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

2.9 How many hours per day do you normally spend on training on the field or road?

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

2.10 Do you spend any time on psychological preparation for badminton and competitions?

Never	*Sometimes	*Often	*Always
-------	------------	--------	---------

*** Please specify the type of psychological preparation you do if you marked any of the above-mentioned options:**

MEDICAL INFORMATION

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

Head/Neck:
Shoulder/Clavicle:
Arm/Elbow/Wrist/Hand:
Back:
Hip/Pelvis:

Thigh/Knee:
Lower leg/Ankle/Foot:

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

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

COMPETITION DATA

4.1 At what level are you competing this year?

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

Club:	Provincial:	National:	International:
-------	-------------	-----------	----------------

4.3 How many matches, approximately, have you played?

Club:	Provincial/National:	International:
-------	----------------------	----------------

4.4 What were the highest achievements you attained during the past two years (2013/14)?

Achievement	Competition	Date

NAME AND SURNAME: _____

1ST MATCH – DATE AND TIME OF MATCH: _____	
TEST COMPONENT	VALUES
SINGLES (S) / DOUBLES (D) / MIXED DOUBLES (M)	
GPS MONITOR NUMBER (LONG AND SHORT)	
POLAR TRANSMITTER NUMBER	
TIME - START OF MATCH (H:MIN)	
TIME DURATION BEFORE FIRST BREAK (SEC)	
BREAK 1 (H:MIN)	
TIME DURATION BEFORE SECOND BREAK (SEC)	
BREAK 2 (H:MIN)	
TIME DURATION BEFORE THIRD BREAK (SEC)	
BREAK 3 (H:MIN)	
TIME DURATION BEFORE FOURTH BREAK (SEC)	
BREAK 4 (H:MIN)	
TIME DURATION BEFORE FIFTH BREAK (SEC)	
BREAK 5 (H:MIN)	
TIME DURATION BEFORE SIXTH BREAK (SEC)	
BREAK 6 (H:MIN)	
TIME - END OF MATCH (H:MIN)	

2ND MATCH – DATE AND TIME OF MATCH: _____	
SINGLES (S) / DOUBLES (D) / MIXED DOUBLES (M)	
GPS MONITOR NUMBER (LONG AND SHORT)	
POLAR TRANSMITTER NUMBER	
TIME - START OF MATCH (H:MIN)	
TIME DURATION BEFORE FIRST BREAK (SEC)	
BREAK 1 (H:MIN)	
TIME DURATION BEFORE SECOND BREAK (SEC)	
BREAK 2 (H:MIN)	
TIME DURATION BEFORE THIRD BREAK (SEC)	
BREAK 3 (H:MIN)	
TIME DURATION BEFORE FOURTH BREAK (SEC)	
BREAK 4 (H:MIN)	
TIME DURATION BEFORE FIFTH BREAK (SEC)	
BREAK 5 (H:MIN)	
TIME DURATION BEFORE SIXTH BREAK (SEC)	
BREAK 6 (H:MIN)	
TIME - END OF MATCH (H:MIN)	

NAME AND SURNAME: _____

3 RD MATCH – DATE AND TIME OF MATCH: _____	
TEST COMPONENT	VALUES
SINGLES (S) / DOUBLES (D) / MIXED DOUBLES (M)	
GPS MONITOR NUMBER (LONG AND SHORT)	
POLAR TRANSMITTER NUMBER	
TIME - START OF MATCH (H:MIN)	
TIME DURATION BEFORE FIRST BREAK (SEC)	
BREAK 1 (H:MIN)	
TIME DURATION BEFORE SECOND BREAK (SEC)	
BREAK 2 (H:MIN)	
TIME DURATION BEFORE THIRD BREAK (SEC)	
BREAK 3 (H:MIN)	
TIME DURATION BEFORE FOURTH BREAK (SEC)	
BREAK 4 (H:MIN)	
TIME DURATION BEFORE FIFTH BREAK (SEC)	
BREAK 5 (H:MIN)	
TIME DURATION BEFORE SIXTH BREAK (SEC)	
BREAK 6 (H:MIN)	
TIME - END OF MATCH (H:MIN)	

4TH MATCH – DATE AND TIME OF MATCH: _____	
TEST COMPONENT	VALUES
SINGLES (S) / DOUBLES (D) / MIXED DOUBLES (M)	
GPS MONITOR NUMBER (LONG AND SHORT)	
POLAR TRANSMITTER NUMBER	
TIME - START OF MATCH (H:MIN)	
TIME DURATION BEFORE FIRST BREAK (SEC)	
BREAK 1 (H:MIN)	
TIME DURATION BEFORE SECOND BREAK (SEC)	
BREAK 2 (H:MIN)	
TIME DURATION BEFORE THIRD BREAK (SEC)	
BREAK 3 (H:MIN)	
TIME DURATION BEFORE FOURTH BREAK (SEC)	
BREAK 4 (H:MIN)	
TIME DURATION BEFORE FIFTH BREAK (SEC)	
BREAK 5 (H:MIN)	
TIME DURATION BEFORE SIXTH BREAK (SEC)	
BREAK 6 (H:MIN)	
TIME - END OF MATCH (H:MIN)	

NAME AND SURNAME: _____

5 TH MATCH – DATE AND TIME OF MATCH: _____	
TEST COMPONENT	VALUES
SINGLES (S) / DOUBLES (D) / MIXED DOUBLES (M)	
GPS MONITOR NUMBER (LONG AND SHORT)	
POLAR TRANSMITTER NUMBER	
TIME - START OF MATCH (H:MIN)	
TIME DURATION BEFORE FIRST BREAK (SEC)	
BREAK 1 (H:MIN)	
TIME DURATION BEFORE SECOND BREAK (SEC)	
BREAK 2 (H:MIN)	
TIME DURATION BEFORE THIRD BREAK (SEC)	
BREAK 3 (H:MIN)	
TIME DURATION BEFORE FOURTH BREAK (SEC)	
BREAK 4 (H:MIN)	
TIME DURATION BEFORE FIFTH BREAK (SEC)	
BREAK 5 (H:MIN)	
TIME DURATION BEFORE SIXTH BREAK (SEC)	
BREAK 6 (H:MIN)	
TIME - END OF MATCH (H:MIN)	

6 TH MATCH – DATE AND TIME OF MATCH: _____	
TEST COMPONENT	VALUES
SINGLES (S) / DOUBLES (D) / MIXED DOUBLES (M)	
GPS MONITOR NUMBER (LONG AND SHORT)	
POLAR TRANSMITTER NUMBER	
TIME - START OF MATCH (H:MIN)	
TIME DURATION BEFORE FIRST BREAK (SEC)	
BREAK 1 (H:MIN)	
TIME DURATION BEFORE SECOND BREAK (SEC)	
BREAK 2 (H:MIN)	
TIME DURATION BEFORE THIRD BREAK (SEC)	
BREAK 3 (H:MIN)	
TIME DURATION BEFORE FOURTH BREAK (SEC)	
BREAK 4 (H:MIN)	
TIME DURATION BEFORE FIFTH BREAK (SEC)	
BREAK 5 (H:MIN)	
TIME DURATION BEFORE SIXTH BREAK (SEC)	
BREAK 6 (H:MIN)	
TIME - END OF MATCH (H:MIN)	

24-HOUR RECALL QUESTIONNAIRE

24-HOUR RECALL

Subject number: _____

Interviewer: _____

Tick what the day was yesterday:

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday
--------	--------	---------	-----------	----------	--------

Would you describe the food that you ate yesterday as typical of your habitual food intake?

Yes	1	No	2
-----	---	----	---

I want to find out about everything you ate or drank yesterday, including water or food you pick from the veld. Please tell me everything you ate from the time you woke up to the time you went to sleep. I will also ask you where you ate the food and how much you ate.

Time (approximately)	Place (Home, school, etc)	Description of food and preparation method	Amount	Amount in g (office use only)	Code (office use only)
From waking up to starting the day's activities					
During the morning					

Time (approximately)	Place (Home, school, etc)	Description of food and preparation method	Amount	Amount in g (office use only)	Code (office use only)
Middle of the day (Lunch time)					
During the afternoon					
At night (dinner time)					
After dinner, before going to sleep					
Do you take any vitamins (tablets or syrup)?			Yes	1	No 2
Give the brand name and dose of the vitamin/tonic:					

APPENDIX I: INSTRUCTIONS FOR AUTHORS OF THE JOURNAL OF STRENGTH AND CONDITIONING RESEARCH

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). Regarding authorship, each contributor should have played a role in at least two of the following areas: research concept and study design, literature review, data collection, data analysis and interpretation, statistical analyses, writing of the manuscript, or reviewing/editing a draft of the manuscript.

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 Acknowledgment portion of the paper or anywhere else in the manuscript.

3. Abstract and Key Words

On a separate page, 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, and should include a statement denoting the level of significance set for the study (i.e. $p \leq 0.05$).

4. Text

The text must contain the following sections with titles in ALL CAPS (i.e. INTRODUCTION, METHODS, RESULTS, DISCUSSION, PRACTICAL APPLICATIONS, ACKNOWLEDGMENTS, and REFERENCES) in this exact order:

A. Introduction. This section is a careful development of the hypotheses of the study leading to the clear purpose of the investigation. It should include the practical question that forms the basis of

the study and how it may influence strength and conditioning practices. In most cases use no subheadings in this section and try to limit it to 4 - 6 concisely written paragraphs. The subject matter does not have to be exhaustively reviewed in this section.

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; "Participants," where the authors include the Institutional Review Board or Ethics Committee approval of their project and appropriate informed consent has been gained. Eligibility criteria for subject selection should be included in the manuscript. Authors should include relative descriptive information such as age, height, body mass, and when appropriate the training status and training history of the participants, e.g. years of training or sport experience. When appropriate, dietary controls and supervision should be described. 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. Authors should describe the research design used in the study. Training programs and testing methods used should be described in detail. Authors are strongly encouraged to include a Control group/condition when appropriate. If a Control group/condition is not used, authors MUST provide test-retest reliability coefficients of the measures used during protocols involving multiple testing periods. Test-retest reliability data should be generated from the authors' laboratory and not merely cited from literature obtained in other laboratories. Additionally, reviewers will look for experimental control for time of day, hydration, sleep and nutritional status. "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., $\rho \leq 0.05$). 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. Authors should report effect sizes and confidence intervals when appropriate. Traditional statistical procedures must be used. The magnitude-based inference (MBI) approach may be used BUT ONLY IN CONJUNCTION with traditional methods.

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. Authors should not replicate data present in the text in tables or figures.

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. Authors should emphasize the new and unique findings of the study. Conclusions should be supported by the data presented. 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 should reflect the answer to the question posed in the Introduction. 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. It is acceptable to cite a published Research Abstract ONLY if it is a sole source of information in that specific scientific area. JSCR forbids the citation of manuscripts published on preprint servers. For journal entries with 6 or more co-authors, please list the first 3 names followed by "et al." When citing chapters within an edited textbook, authors MUST specifically cite the chapter author names (not the editors). Authors must also include the chapter name and page range for all book references. 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. For End Note Users, the software currently is using an older style of formatting for JSCR references. It is recommended that authors update the final reference list by either manually checking each reference to ensure proper formatting or updating their End Note software. To update the software, End Note users may edit "Output Styles" for JSCR and save the changes. Users may click "Citations" and "Author Lists" to edit "Author Separators" "and" "Abbreviated Author List". This will allow users to remove the term "and" and use "et al." for referencing. Questions regarding End Note use or software editing are directed to Clarivate support at 1-800-336-4474. If using End Note please double-check citations and make sure journal article titles do not have all words capitalized and journal titles are abbreviated properly and italicized.

Below are several examples of references:

Journal Article

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

Kraemer, WJ, Hatfield DL, Comstock, BA, et al. Influence of HMB supplementation and resistance training on cytokines responses to resistance exercise. *J Am Coll Nutr* 33: 247-255, 2014.

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 $\frac{1}{2}$ software_. University of Queensland, 1992.

Proceedings

Viru, A, Viru, M, Harris, R, Oopik, V, Nurmekivi, A, Medijainen, L, 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.

6. Acknowledgments

In this section you can place the information related to identification of funding sources; current contact information of corresponding author; and gratitude to other people involved with the conduct of the experiment. In this part of the paper the conflict of interest information must be

included. In particular, authors should: 1) Disclose professional relationships with companies or manufacturers who will benefit from the results of the present study, 2) Cite the specific grant support for the study and 3) State that the results of the present study do not constitute endorsement of the product by the authors or the NSCA. Failure to disclose such information could result in the rejection of the submitted manuscript.

APPENDIX J: EXAMPLE OF ARTICLE PUBLISHED IN THE JOURNAL OF STRENGTH AND CONDITIONING RESEARCH

Associations Between Heart Rate Variability-Derived Indexes and Training Load: Repeated Measures Correlation Approach Contribution

Ksenya Davletyarova,¹ Philippe Vacher,² Michel Nicolas,² Leonid V. Kapilevich,^{1,3,4} and Laurent Mouroit^{1,5}

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Abstract

Davletyarova, K, Vacher, P, Nicolas, M, Kapilevich, LV, and Mouroit, L. Associations between heart rate variability-derived indexes and training load: repeated measures correlation approach contribution. *J Strength Cond Res* XX(X): 000–000, 2020—This study aimed to evaluate whether similar associations between indexes derived from heart rate variability (HRV) analyses and training load (TL) could be obtained by using the commonly used Pearson correlation technique and the repeated measures correlation (rmcorr). Fourteen well-trained swimmers (18.5 ± 1.6 years) participated. The training period lasted 4 weeks with a gradual increase in TL. Daily external TL (exTL) and internal TL (inTL) were summed to obtain a weekly TL, and HRV analyses were performed every Saturday morning. During the 4-week period, exTL and inTL increased ($p < 0.05$) together with a decrease ($p < 0.05$) in heart rate and an increase ($p < 0.05$) of cardiac parasympathetic indexes. No significant correlation was found using Pearson correlation while significant associations were found using rmcorr; considering exTL, positive (mean R-R interval [MeanRR], root mean square of differences between successive RR interval [RMSSD], low frequency [LF], high frequency [HF], instantaneous beat-to-beat variability [SD1], continuous beat-to-beat variability [SD2], SD1/SD2; r from 0.59 to 0.46, p value from <0.001 to 0.002) and negative (mean heart rate [meanHR]; $r = -0.55$, $p < 0.001$) associations were found. Considering inTL, positive (MeanRR, RMSSD, LF, HF, HFnu, SD1, SD2, SD1/SD2; r from 0.56 to 0.34, p -value from <0.001 to 0.025) and negative (meanHR, LFnu, LF/HF; r from -0.49 to -0.34 , p value from 0.001 to 0.025) associations were found. The rmcorr statistical method was able to show associations between parasympathetic indexes and TL contrary to Pearson correlation analysis. Because rmcorr is specifically designed to investigate within-individual association for paired measures assessed on 2 or more occasions for multiple individuals, it should constitute a tool for future training monitoring researches based on a repeated-measures protocol.

Key Words: multiple correlation method, statistic, training monitoring, athletes

Introduction

Monitoring athletes' external (objective measures of the work performed by the athlete during training or competition; external training load [exTL]) and internal (relative physiological or psychological stressors imposed on the athlete during training or competition; internal training load [inTL]) training load (TL) is crucial for assessing whether they are adapting properly to their training program, for evaluating if the balance between exercise training and recovery is optimal, and, ultimately, for improving sport performance (8,21,25). Depending on the context of the program to which they are applied and the objectives to be achieved, several monitoring methods have been proposed with their own inherent strengths and limitations. Heart rate (HR)-derived indexes, such as HR variability (HRV) or HR recovery, required low cost hardware and software and have the advantage of being independent of location and activity (3,8). Despite having limitations in data interpretation and direct use to prescribe training,

they have been highlighted as having a great potential and have been largely used for monitoring training adaptations (2,5,8,13).

Although investigating associations between HR-derived indexes and TL during a training period (i.e., repeated measures of the same variables in the same subjects), regression/Pearson correlation is commonly used. When relative change over a training period is considered (i.e., simple pre-training to post-training evaluation), data from a specific subject are used only one time to evaluate the strength of the correlation (i.e., association between relative pre-post training changes in HRV indices, and a relative pre-post training change in TL is calculated using one data point per subject; e.g., (9)). But most of the time, multiple use of the same data in a specific subject is used for calculation. For example, in the previously cited study, the authors calculated correlations between baseline data and the change over the training period, i.e., using the baseline data a second time in the relative change calculation (9). This procedure is common (15,24,31). The use of multiple recordings on a specific subject could also be performed using absolute data recorded once pre-training and once post-training (26,34) or using relative changes but over multiple time points (10,16). Analyzing nonindependent data

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Barryard et al. (3) reported that the load-velocity relationship in a free-weight back squat did not accurately predict 1RM. Similarly, Hughes et al. (21) demonstrated that p1RM significantly overestimated measured back squat 1RM using the LVP and MCV_{100%} method. Although these studies concluded that the load-velocity relationship did not accurately predict 1RM, the predictions were highly reliable and demonstrated strong associations with measured 1RM ($r > 0.90$). Furthermore, back squat p1RM and 1RM remained strongly correlated 24 hours after a high-volume back squat protocol; however, the load-velocity relationship significantly overpredicted 1RM (20). The previously mentioned studies have examined the free-weight back squat exercise, and it is known that the load-velocity relationship is exercise specific (11). Velocity predictions have accurately predicted the 1RM for upper-body pulling exercises, and velocity-predictions were more accurate than repetition-to-failure prediction equations (31). Jidovtseff et al. (23) reported the load-velocity relationship to be a valid measure of predicting bench press 1RM; however, this study used the Smith machine bench press, which is kinetically and kinematically different from the more commonly used free-weight bench press (7). Currently, it is unknown whether the same results would apply to a free-weight bench press, and more research is warranted to examine if the load-velocity relationship can accurately predict 1RM and be used to determine daily preparations. Therefore, the primary purpose of this study was to (a) determine the effect of an overload microcycle and taper on bench press MCV and 1RM and (b) determine if the load-velocity relationship can accurately predict free-weight bench press 1RM. It was hypothesized that the MCV for the LVPs and bench press 1RM would decrease after the overload microcycle and return to baseline or increase after the taper. Additionally, we hypothesized that there would be no difference between p1RM and 1RM across each testing session, and the variables would be strongly correlated.

Methods

Experimental Approach to the Problem

This study examined the effect of an overload microcycle and taper on the load-velocity relationship and maximal strength for the bench press. Subjects completed 3 microcycles of resistance training consisting of an introduction week, an overload week, and a taper week. At the end of each microcycle, subjects completed bench press velocity and strength assessments. Based on the recommendations of Jovanovic and Hargan (24), individual LVPs were developed for each subject by completing repetitions at 40, 55, 70, and 85% of 1RM. The highest MCV was recorded for each set and used to establish the subject's LVP. Following these warm-up sets, subjects completed an 1RM assessment. The MCV of the successful 1RM attempt was recorded as the MCV_{100%}. Using the LVP (MCV₄₀, MCV₅₅, MCV₇₀, and MCV₈₅) and the MCV_{100%}, a p1RM was calculated for each subject (24). The same protocol was completed during the test sessions at the end of each microcycle. A new 1RM was attempted during each test session, whereas the loads used during the individualized LVPs remained constant.

Subjects

Thirteen male powerlifters volunteered to participate in this study, but 1 subject was excluded because of noncompliance with testing procedures. Twelve male powerlifters (age, 24.2 ± 5.6 years; height, 178.8 ± 5.4 cm; body mass, 98.7 ± 14.2 kg; body fat, $2.8 \pm 5.2\%$; relative bench press 1RM, 1.5 ± 0.2 ; Height, body mass, and age were listed as mean $\pm$ SD) completed the study. Subjects were

recruited from the university's student population and a local powerlifting training center. All subjects were healthy, nonsmoking volunteers who evidenced no cardiovascular, metabolic, or musculoskeletal disease (2). To minimize any confounding effects associated with age-related differences in skeletal muscle recovery between younger and older individuals, only subjects between the ages of 18–40 years were included in this study (29).

All prospective subjects completed an exercise screening questionnaire, PAR-Q, and health history questionnaire to determine if they met the inclusion criteria. To qualify for inclusion in the study, subjects had to have at least 1 year of resistance training experience and meet the national qualifying requirements for drug-tested athletes established by the United States Powerlifting Association (1). The powerlifting totals were self-reported by subjects based on the most recent competition or strength testing session. Additionally, subjects could not have competed in a powerlifting competition or peaking program within the 4 weeks before participating in this study. Before participation, all subjects signed a written informed consent document approved by the local institutional review board. Study was approved by IRB at the University of Alabama.

Experimental Protocols. During the initial visit, subject's standing height (to the nearest 0.1 cm) was measured using a stadiometer (SECA 67310; SECA, Chino, CA) and body mass (to the nearest 0.1 kg) was measured using a digital scale (Tanita BWB-800; Tanita, Arlington Heights, IL). Body composition was assessed under nonfasted conditions using dual-energy X-ray absorptiometry (Lunar Prodigy; General Electric Healthcare, Madison, WI). Subjects were provided instruction regarding the resistance training program and performance measures administered during the study.

Procedures

Resistance Training Protocol. Within 1 week after the initial visit, subjects reported to a weight training facility to begin the 3-week resistance training program. The training program consisted of an introduction microcycle, an overload microcycle, and a taper microcycle. Before participating in each training session, each subject's perceptual recovery was determined using the perceived recovery status (PRS) scale (26). After indicating their perceived recovery, subjects completed a full-body, dynamic warm-up that was standardized across each session. All training sessions were monitored by a certified strength and conditioning specialist.

The introduction microcycle consisted of 3 nonconsecutive days over a 3-day period using a total-body program (Table 1). Training loads were determined using the rating of perceived exertion (RPE) scale based on repetitions in reserve. This scale has been validated as a method of gauging resistance training intensity in novice and experienced lifters (17,37). During the introduction microcycle, subjects were instructed to complete the prescribed number of repetitions for each set at an RPE of 6 to 8. On the fifth day of the introduction week, baseline (BL) tests were performed before completing the third resistance training session. Before arrival at each test session, subjects were instructed to refrain from caffeine at least 12 hours and alcohol at least 24 hours before testing.

Two days after BL, subjects began an overload microcycle of resistance training, with the purpose of overreaching. Resistance training was performed on 4 consecutive days using a total-body program (Table 1). Daily undulations in training volume and intensity were programmed to include high-load and high-volume training as a means of inducing central and peripheral fatigue. All

Table 1
Resistance training during the introduction, overload, and taper microcycle.^a

	Day 1	Day 2	Day 3	Day 4	Day 5
Introduction microcycle ^b	Back squat, 3 × 5 Bench press, 3 × 5 RDL, 3 × 8 Standing OHP, 3 × 8 Lat pulldown, 3 × 8	No resistance training	Deadlift, 3 × 5 Bench press, 3 × 5 Leg press, 3 × 8 Seated OHP, 3 × 8 Barbell row, 3 × 8	No resistance training	Baseline testing Back squat, 3 × 3 RDL, 3 × 5 Standing OHP, 3 × 8 Lat pulldown, 3 × 8
Overload microcycle	Back squat, 3 × 8RM Bench press, 3 × 8RM RDL, 3 × 10RM Standing OHP, 3 × 10RM Lat pulldown, 3 × 10RM	Deadlift, 5 × 5RM Bench press, 4 × 7RM Leg press, 3 × 10RM Seated OHP, 3 × 10RM Barbell row, 3 × 10RM	Back squat, 5 × 5RM Bench press, 5 × 5RM RDL, 3 × 8RM Standing OHP, 3 × 8RM Pull-up, 3 × 8RM	Deadlift, 5 × 3RM Bench press, 7 × 5RM Leg press, 3 × 8RM Seated OHP, 3 × 8RM Barbell row, 3 × 10RM	Overload testing
Taper microcycle ^c	Back squat, 3 × 5 Bench press, 4 × 5 RDL, 3 × 8 Standing OHP, 3 × 8 Lat pulldown, 3 × 8	No resistance training	Deadlift, 3 × 5 Bench press, 3 × 3 Leg press, 3 × 8 Seated OHP, 3 × 8 Barbell row, 3 × 8	No resistance training	Taper testing

^aOHP = overhead press; RDL = Romanian deadlift.^bAll sets performed to an RPE 8–9.^cLoad calculated as 90 and 65% of average load used during Days 3 and 4, respectively, of overload microcycle.

sets were performed using repetition maximums, and training loads were adjusted to ensure that all sets were performed to muscular failure. If subjects reached muscular failure before completing the required repetitions for a given set, the load was reduced for subsequent sets to ensure that the desired training volume was obtained. If subjects completed the prescribed repetitions and perceived more repetitions were remaining, loads were increased for the subsequent set. On the fifth day of the overload week (PostOL), subjects completed the same assessments administered during the initial baseline testing session. To minimize any confounding effects for time of day, subjects completed the PostOL assessments within 2 hours of the time of day as completed during BL testing. After the overload test session, subjects received 48 hours of rest before tapering.

The taper microcycle consisted of 2 nonconsecutive days of training over a 4-day period (Table 1). Each day contained the same total-body exercises used in the overload week; however, total training volume was substantially reduced (32). In an attempt to enhance performance, only small reductions in training intensity were programmed. Training loads were adjusted to 90 and 85% of the average load used during the third and fourth training day of the overload week. Taper performance measures were recorded on the fifth day of the taper week (PostTP). Each subject performed the same measures at the same time of day as performed at BL and PostOL.

Internal and External Load Parameters. Before each training and test session, subjects recorded a PRS score. The PRS scale is a subjective rating from 0 to 10, with 0–2 representing poor recovery and anticipating poor performance, 4–6 consisting of moderate recovery and expecting normal performance, and 7–10 representing high recovery and expecting increased performance. This scale has been validated as a useful tool in monitoring fatigue and performance in anaerobic exercise (26,34). The subjects were informed of the purpose of the PRS scale and read specific instructions on how to interpret the scale. Additionally, session RPE (sRPE), a metric capable of quantifying the global rating of internal load (9,28), was collected 15 minutes after the completion of each training session (23). Using a modified CR-10 RPE scale (9), subjects were asked to indicate the difficulty of their workout in which a value near 0 suggests easy training and a value near 10

suggests very hard training. In addition to internal load measures, external loads were calculated to quantify the amount of work performed during each microcycle. Repetition volume was quantified as the total number of repetitions completed. Volume-load was determined by multiplying the load lifted by the repetitions completed in a given set. The bench press and total volume-load was then calculated for each microcycle.

Velocity and Strength Assessments. After the completion of a dynamic warm-up, subjects completed a bench press warm-up protocol to establish an individualized 1RM. All bench press assessments were performed on an instrumented bench (Force Super Bench; Force Strength Systems, Spokane Valley, WA) using a 20.4-kg powerlifting competition barbell (Rogue Fitness, Columbus, OH). Subjects were instructed on how to perform the bench press to meet United States Powerlifting Association (USPA) standards. Hand position on the barbell was recorded for each subject and maintained consistent for each trial.

Subjects began the assessment by performing 5 repetitions with an unloaded barbell. To establish the individualized 1RM, a bench press protocol was developed based on the guidelines of Jovanovic and Hamagan (24). For this protocol, subjects completed 3 repetitions at 40% (MCV₄₀), 2 repetitions at 55% (MCV₅₅), and 1 repetition each at 70% (MCV₇₀) and 85% (MCV₈₅) of previously acquired 1RM. For each repetition, subjects were instructed to perform the concentric phase of the lift as explosively as possible and to maintain a controlled descent during the eccentric phase. Additionally, each subject was required to pause the barbell on the chest for 1 second before initiating the concentric phase of the lift. The MCV of each repetition was measured using a linear position transducer (GymAware PowerTool, GymAware, Kinematic Performance Technology, Canberra, Australia), which has been previously validated for measuring barbell velocity (19). The highest value was selected for MCV₄₀ and MCV₅₅. After each bench press set, subjects reported RPE and were given 2 minutes of rest before performing the next set with an increased load. In addition to determining the MCV for each warm-up set, the average MCV (MCV_{avg}) was calculated for the 1RM by averaging the velocities obtained from each of the warm-up sets.

Two minutes after completing MCV_{BL} , subjects began 1RM bench press attempts. Each attempt was selected by the primary investigator using perceptual feedback from the subject and MCV of the previous attempt. All attempts were required to meet USPA standards. A 1RM was determined based on whether (a) subject reported a 10 RPE and primary investigator agreed that a subsequent attempt would not be successful with a 2.3-kg load increase or (b) subject reported a 9 or 9.5 RPE followed by a failed attempt with a 2.3-kg load increase (17). Rest periods were 5 minutes after each 1RM attempt. All successful 1RM attempts were obtained with 4 attempts or less.

Predicted 1-Repetition Maximum Calculation. Based on the methods outlined by Jovanovic and Flanagan (24), an LVP was established for each subject at BL, PostOL, and PostTP. Additionally, subjects' MCV_{BL} was recorded during the 1RM assessment at BL. Using the LVP for each test session and the baseline MCV_{BL} , individual regression equations were developed using Excel 2013 (Microsoft Corporation, Redmond, WA) to predict 1RM for each testing session.

Statistical Analysis

Data were analyzed using SPSS Statistics version 24.0 (IBM Corporation, Armonk, NY) and Jamovi (version 0.9). A 1-way repeated-measures analysis of variance (ANOVA) was used to compare mean differences in MCV for the LVPs across BL, PostOL, and PostTP. When appropriate, a Tukey's post hoc analysis was used to determine where the mean differences occurred. A 2×3 (condition $\times$ time) repeated-measures ANOVA was used to compare mean differences between the p1RM and 1RM across each of the test sessions, and Tukey post hoc analysis was used to determine where the mean differences occurred. Spearman's rho correlations (ρ) were used to assess the relationship between the p1RM and measured 1RM. Additionally, Spearman's rho was used to determine the association between the percent change in MCV_{AVG} and 1RM across each of the test sessions. Correlation coefficients between 0 and 0.30 were

considered small, 0.31–0.49 moderate, 0.50–0.69 large, 0.70–0.89 very large, and 0.90–1.00 near perfect (18). Additionally, Bland-Altman plots were used to identify the agreement between p1RM and actual 1RM (4). For measures of internal and external load, a 1×3 (test $\times$ time) repeated-measures ANOVA was used to compare mean differences across BL, PostOL, and PostTP sessions. If significance was found, a Tukey's post hoc analysis was performed to determine where differences occurred. Cohen's d effect sizes were calculated and interpreted using the following thresholds: <0.2, trivial; 0.2–0.6, small; 0.6–1.2, moderate; 1.2–2.0, large; 2.0–4.0, very large; and 4.0, extremely large (18). The smallest detectable difference (SD) for MCV_{AVG} , calculated as $1.96 \times \sqrt{2} \times SE$ of measurement for the baseline testing (2), was used to evaluate meaningful change in MCV between microcycles. Data are presented as mean $\pm$ SD, and the level of significance was set at $p \leq 0.05$.

Results

Load-Velocity Comparisons

Velocity measurements for MCV_{BL} , MCV_{OL} , MCV_{TP} , and MCV_{AVG} at BL, PostOL, and PostTP are presented in Table 2. For MCV_{BL} , there was a significant main effect for time ($p = 0.050$; $\eta_p^2 = 0.238$). Multiple comparisons revealed that MCV_{BL} was lower at PostOL compared with PostTP ($p = 0.048$; $d = -0.51$). There was no difference in BL MCV_{BL} compared with PostOL ($p = 0.171$; $d = 0.43$) and PostTP ($p = 0.790$; $d = -0.15$). For MCV_{OL} , there was a significant main effect for time ($p = 0.006$; $\eta_p^2 = 0.574$). Post hoc analysis revealed that MCV_{OL} at PostOL was lower than at BL ($p = 0.008$; $d = -0.60$) and PostTP ($p = 0.021$; $d = -0.53$). There was no difference in MCV_{OL} between BL and PostTP ($p = 0.917$; $d = 0.09$). For MCV_{TP} , there was a significant main effect for time ($p < 0.001$; $\eta_p^2 = 0.551$). Post hoc analysis revealed that MCV_{TP} at PostOL was lower than at BL ($p < 0.001$; $d = -0.84$) and PostTP ($p < 0.001$; $d = -0.83$). There was no difference in MCV_{TP} between BL and PostTP ($p = 0.961$; $d = -0.06$). For MCV_{AVG} , there was a significant main effect for time ($p = 0.003$; $\eta_p^2 = 0.408$). Post hoc analysis revealed that MCV_{AVG}

Table 2. Comparison of external load, internal load, and bench press performance across microcycles ($n = 12$).^a

	Baseline	Post overload	Post taper
External load			
Total volume-load (kg)	29,023.8 $\pm$ 6,440.2	69,731.8 $\pm$ 13,648.3†	19,733.6 $\pm$ 3,868.8†§
Bench press volume-load (kg)	4,880.8 $\pm$ 1,123.3	12,834.5 $\pm$ 2,885.3†	5,238.1 $\pm$ 1,247.0§
Internal load			
Session RPE	5.3 $\pm$ 1.1	8.5 $\pm$ 0.8§	2.3 $\pm$ 1.1†§
RPE	7.2 $\pm$ 0.9	6.3 $\pm$ 1.1§	8.4 $\pm$ 1.2†§
Bench press velocity			
MCV_{BL} (m·s ⁻¹)	0.92 $\pm$ 0.08	0.88 $\pm$ 0.12	0.84 $\pm$ 0.11§
MCV_{OL} (m·s ⁻¹)	0.75 $\pm$ 0.08	0.68 $\pm$ 0.12‡	0.74 $\pm$ 0.09§
MCV_{TP} (m·s ⁻¹)	0.68 $\pm$ 0.07	0.68 $\pm$ 0.12‡	0.68 $\pm$ 0.09§
MCV_{BL} (m·s ⁻¹)	0.38 $\pm$ 0.08	0.32 $\pm$ 0.08‡	0.41 $\pm$ 0.09§
MCV_{AVG} (m·s ⁻¹)	0.66 $\pm$ 0.07	0.68 $\pm$ 0.11‡	0.67 $\pm$ 0.09§
Bench press strength			
Bench press 1RM (kg)	151.0 $\pm$ 22.4	146.7 $\pm$ 16.8	158.1 $\pm$ 21.0§
Bench press p1RM (kg)	150.8 $\pm$ 22.7‡	150.8 $\pm$ 17.3‡	162.2 $\pm$ 22.8§

RPE = perceived exertion; RPE = rating of perceived exertion; 1RM = 1-repetition maximum; p1RM = predicted 1-repetition maximum; MCV_{BL} = mean concentric velocity at 60% 1RM; MCV_{OL} = mean concentric velocity at 60% 1RM; MCV_{TP} = mean concentric velocity at 60% 1RM; MCV_{AVG} = mean concentric velocity at 60% 1RM.

^aData presented as mean $\pm$ SD.

‡Significantly different from baseline ($p < 0.05$).

‡Significantly different from PostOL ($p < 0.05$).

§Significantly different from 1RM ($p < 0.05$).

at PostOL was lower than at BL ($p = 0.045$; $d = -0.62$) and PostTP ($p = 0.003$; $d = -0.78$). There was no difference in MCV_{BL} between BL and PostTP ($p = 0.433$; $d = -0.31$). For MCV_{AVG} , there was a significant main effect for time ($p = 0.002$; $\eta_p^2 = 0.437$). Post hoc analysis revealed that MCV_{AVG} was lower at PostOL compared with BL ($p = 0.010$; $d = -0.67$) and PostTP ($p = 0.003$; $d = -0.71$). There was no difference in MCV_{AVG} between BL and PostTP ($p = 0.443$; $d = -0.31$).

Individual changes in MCV and 1RM between microcycles are presented in Figure 1. The change in MCV_{AVG} was associated with the change in 1RM from PostOL to PostTP ($r = 0.61$; $p = 0.040$). There were no significant relationships between changes in MCV_{AVG} and 1RM from BL to PostOL ($r = 0.52$; $p = 0.084$), as well as BL to PostTP ($r = 0.56$; $p = 0.058$). The SDD of MCV_{AVG} was calculated as ± 0.07 in s^{-1} . Five subjects recorded MCV_{AVG} below the SDD at PostOL. At PostTP, one subject's MCV_{AVG} fell below the SDD threshold and one subject performed above the threshold compared with BL values.

One-Repetition Maximum and Predicted Comparison

Comparisons of 1RM and p1RM values are depicted in Table 2. There was no condition (1RM vs. p1RM) $\times$ time (test session) interaction effect ($p = 0.243$; $\eta_p^2 = 0.113$). There was a significant main effect for condition ($p = 0.010$; $\eta_p^2 = 0.347$). Post hoc comparisons revealed that p1RM was higher than measured 1RM ($p = 0.010$; $d = 0.18$ – 0.35). There was a significant main effect for time ($p < 0.001$; $\eta_p^2 = 0.617$). PostOL values were lower than BL ($p = 0.004$; $d = -0.21$ to -0.40) and PostTP ($p < 0.001$; $d = -0.46$ to -0.60). There was no difference between BL and PostTP ($p = 0.074$; $d = -0.13$ to -0.20).

Bland-Altman plots showing agreement between measured 1RM and p1RM during BL, PostOL, and PostTP are presented in Figure 3. The 95% confidence intervals (constant error ± 1.96 SD of residual scores [p1RM–1RM]) ranged from 21.4 above to -3.8 below the constant error of 7.8 kg during BL, 20.0 above to -13.2 below the constant error of 7.8 kg during OL, and 24.4 above to -12.2 below

the constant error of 6.1 kg during taper testing. There was no correlation between the difference and mean of the p1RM and 1RM ($p > 0.05$) for any test session, suggesting no proportional biases existed. Very large to near perfect correlations existed between p1RM and 1RM at BL ($r = 0.93$; $p < 0.001$), PostOL ($r = 0.89$; $p < 0.001$), and PostTP ($r = 0.96$; $p < 0.001$).

Internal and External Loads. Total volume-load, bench press volume-load, session RPE, and PRS values are presented in Table 2. For total volume-load, there was a significant main effect for time ($p < 0.001$; $\eta_p^2 = 0.960$). Multiple comparisons revealed that total volume-load was higher during the overload microcycle compared with the introduction microcycle ($p < 0.001$; $d = 2.90$) and taper ($p < 0.001$; $d = 4.00$). Total volume-load was higher during the introduction microcycle compared with the taper ($p < 0.001$; $d = -1.72$). For bench press volume-load, there was a significant main effect for time ($p < 0.001$; $\eta_p^2 = 0.979$). Post hoc analysis revealed that bench press volume-load was higher during the overload microcycle compared with the introduction microcycle ($p < 0.001$; $d = 3.63$) and taper ($p < 0.001$; $d = 3.17$). Bench press volume-load was not different between the introduction microcycle and taper ($p = 0.395$; $d = -0.37$). For session RPE, there was a significant main effect for time ($p < 0.001$; $\eta_p^2 = 0.887$). Multiple comparisons showed that session RPE was higher during the overload microcycle compared with the introduction microcycle ($p < 0.001$; $d = 3.17$) and taper ($p < 0.001$; $d = 4.43$). Session RPE was higher during the introduction microcycle compared with the taper ($p < 0.001$; $d = -1.77$). For perceived recovery, there was a significant main effect for time ($p < 0.001$; $\eta_p^2 = 0.740$). Multiple comparisons showed that PRS was lower at PostOL compared with BL ($p < 0.001$; $d = -1.60$) and PostTP ($p < 0.001$; $d = -1.65$). PRS was higher at PostTP compared with BL ($p = 0.018$; $d = 1.03$).

Discussion

The results of the current study indicate that bench press MCV decreased after the overload microcycle and return to baseline

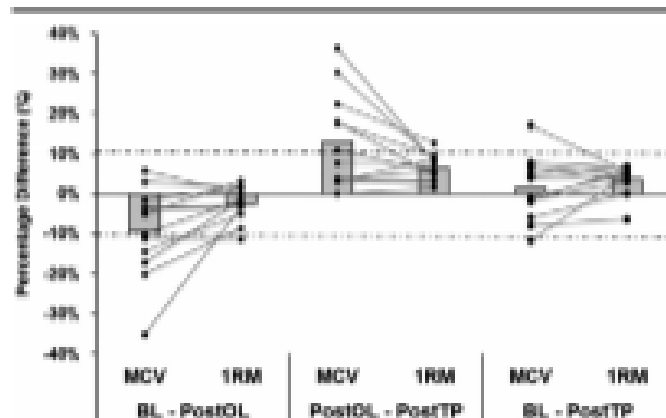


Figure 1. Percentage difference in mean concentric velocity (MCV) of the individual load-velocity profiles and bench press 1-repetition maximum (1RM) between microcycles. Mean concentric velocity was calculated as the percentage difference in the MCV_{avg} for the subjects' load-velocity profile. The dashed line represents the smallest detectable difference (SDD) in MCV ($\pm 10.9\%$) calculated from the baseline load-velocity profiles. Mean concentric velocity values above or below the dashed line indicate meaningful changes in MCV between microcycles. BL = baseline testing; PostOL = post-overload testing; PostTP = post-taper testing.

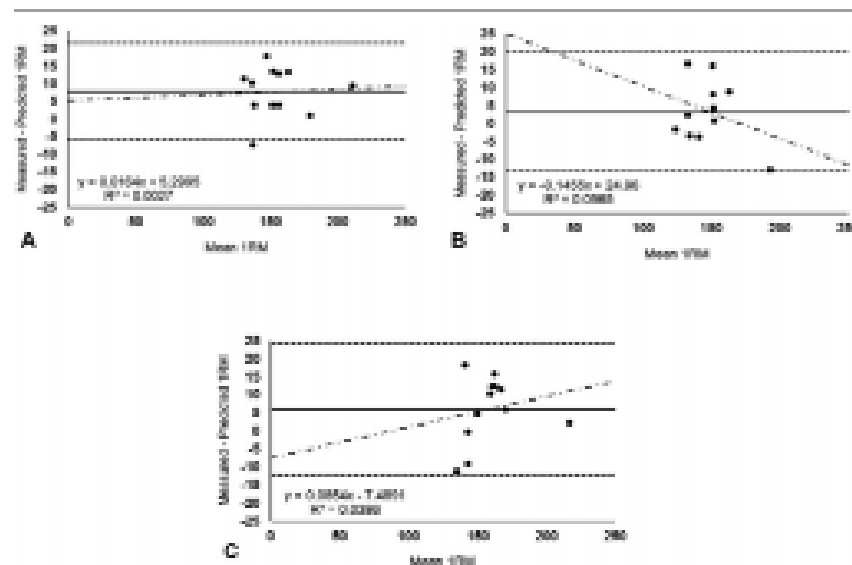


Figure 2. Bland-Altman plots comparing the agreement between measured 1-repetition maximum (1RM) and predicted 1RM (p1RM) during the (A) baseline, (B) post-overload, and (C) post-taper first sessions. Mean 1RM was calculated as (measured 1RM + p1RM)/2. The solid lines represent the mean bias, whereas the horizontal dashed lines represent the 95% limits of agreement. The dashed dotted regression lines represent the trend between the differences and means, and accompanying regression equations with coefficients of determination (R^2) are presented.

following the taper. Bench press 1RM remained unchanged after the overload microcycle, but following the taper, it increased above PostOL values. Furthermore, p1RM overestimated measured 1RM (2.3–5.1%) across each of the microcycles; however, near-perfect correlations were observed between predicted and measured 1RM.

The overload microcycle consisted of high-volume and high-load training using total-body, multipoint resistance exercises. This programming strategy is used as a means of overreaching, which results in impaired neuromuscular function and performance (14,15). In the current study, measurements of internal load suggested high levels of perceived exertion during the overload microcycle, resulting in decreased PRS scores at PostOL. Previous research has reported a significant relationship between PRS scores and markers of muscle damage (34). In addition to decreased perceived recovery, subjects in the current study experienced significant decreases in MCV_{10} , MCV_{20} , MCV_{40} , and MCV_{60} after the overload microcycle, suggesting neuromuscular fatigue. Similarly, Rander et al. found perceived recovery and neuromuscular function (i.e., CMJ) to decrease after 6 days of intensified resistance training (35). Furthermore, the intensified training caused significant reductions in measurements of muscular strength. In a study by Hughes et al., a fatiguing back squat protocol increased perceived soreness and decreased back squat 1RM and velocity-predicted 1RM for up to 48 hours (20). The current study did not find a significant difference in bench press 1RM between BL and PostOL; however, effect size calculations suggested a small decrease (–2.6%) after the overload microcycle. The previous studies used lower-body exercises (i.e., back squat) to assess muscular strength (20,33), whereas the current

study examined the bench press exercise, which is predominantly an upper-body exercise. Based on previous findings, bench press and back squat recovery follows a similar time course with sub-maximal loads (30), but it is unknown how maximal strength recovery differs between exercises.

It has been suggested that carefully planned periods of overload, followed by a taper, can result in a phenomenon known as the “rebound effect” (12). Based on the fitness-fatigue model, a reduction in training volume allows for fatigue to dissipate at a faster rate than fitness, resulting in the enhanced preparedness (32). In the present study, the taper consisted of significantly lower training volumes compared with the overload microcycle. This reduction in training volume allowed for enhanced recovery noted by significantly higher perceived recovery compared with the PostOL. These improvements in internal load parameters were supported by increases in bench press performance. Also, MCV for the LVPs were significantly higher compared with PostOL and had returned back to BL. Similarly, the taper produced a significant increase in 1RM compared with the PostOL 1RM. Furthermore, there was no significant difference in MCV and 1RM between PostTP and BL; however, effect size calculations suggest a small increase in 1RM. Previous research demonstrated that 1RM bench press increased by 2% in elite Rugby ball players after a 16-week training program and 4-week taper (22). In the present study, PostTP bench press 1RM increased by 6.5 and 3.6% compared with PostOL and BL. Additionally, PostTP bench press MCV_{60} increased by 13.1% above PostOL, whereas only a 1.4% increase was observed above BL. Similar findings have been reported in countermovement jump performance when 3 days of recovery followed a 6-day intensified

resistance training microcycle (3,3). In the current study, MCV was more sensitive to changes in training loads than maximal strength. Previous research has demonstrated that measures of velocity and power decrease to a greater extent than dynamic maximal strength after intensified resistance training (13,15). This may explain the significant moderate decrease in MCV_{AVG} . Based on these results, changes in velocity may be early indicators of neuromuscular fatigue. Furthermore, it is possible that the duration of the overload microcycle was not long enough to cause significant decreases in maximal strength. For example, a previous study showed that maximal strength was impaired after 6 days of intensified resistance training consisting of 2 training sessions per day (33). Similarly, Fry et al. noted strength decreases after a 2-week overreaching protocol (14). A longer period of overload than the 4 days used in the present study may have produced greater reductions in dynamic maximal strength.

Individualized LVPs have demonstrated high reliability when recording the MCV of loads ranging from 20 to 90% 1RM (2). Because of the high reliability, MCV has been suggested as a method to assess daily readiness and autoregulate training. To determine meaningful changes in MCV, it has been recommended to calculate the SDD and only make load adjustments for velocities that fell outside of the SDD range (2). In the current study, the SDD for MCV_{AVG} was calculated as $0.07 \text{ m}\cdot\text{s}^{-1}$. After the overload microcycle, 5 subjects experienced MCV_{AVG} below the SDD range. Furthermore, each of these subjects experienced a decrease in 1RM (-2.3 to -20.4 kg) at PostOL. This would indicate that MCV was able to detect changes in neuromuscular performance and daily readiness of maximal strength. The remaining 7 subjects recorded MCV_{AVG} values within the SDD at PostOL, and maximal strength was variable (-6.8 to $+4.5$ kg). Based on these results, velocities that fell within the SDD make it unclear whether maximal strength is changed. Following the taper, one subject recorded MCV_{AVG} above the SDD, whereas one subject's MCV_{AVG} remained below the SDD. Both subjects experienced increased 1RM compared with baseline ($+6.8$ to $+9.1$ kg). These results suggest that MCV may be a useful tool to autoregulate training; however, incorporating other measures (i.e., RPE) may improve the decision-making process.

This is the first study examining the utility of the load-velocity relationship to predict 1RM in the free-weight bench press across microcycles of varying training loads. Previous studies investigating 1RM predictions based on load-velocity relationships were performed using a Smith machine (6,16,21). Using an undisclosed equation, Bouquet et al. predicted 1RM Smith machine bench press in a group of physical education students and teachers (6). Measured 1RM and p1RM were significantly different and p1RM consistently underpredicted 1RM by 3.4 kg. This differs from the findings of the present study wherein p1RM overpredicted actual 1RM by 3.4–7.8 kg. Furthermore, the 95% limits of agreement ranged from 20.0–24.4 kg above and 5.8–13.2 kg below the constant error. The large spread suggests that predicting bench press 1RM from the load-velocity relationship is inaccurate because of the large variability in p1RM values. For example, based on the limits of agreement from BL, one could be 95% confident that a lifter with an p1RM bench press of 150 kg would have an actual 1RM between 144.2 kg ($150.0-5.8$ kg) and 171.4 kg (150.0 kg $+ 21.4$ kg). Because of the large variability in predicting 1RM, it is not recommended that this method be used to replace measured 1RM for programming purposes and practitioners should be aware that kinematic differences between free-weight and machine-based exercises may produce discrepant results.

It has been suggested that a p1RM derived from an individual LVP can be used to determine daily preparedness (24). In the current study, p1RM and 1RM were lower at PostOL compared with BL. After the taper, p1RM and 1RM increased above PostOL and BL. Additionally, the relationship between p1RM and 1RM during each test session was very large to near perfect. Based on these results, calculating a daily p1RM may serve as a practical monitoring tool. Currently, a repetitions-to-failure or RM assessment is the most common method for assessing fatigue and adaptation during resistance training. Several regression equations have been developed to predict 1RM based on the number of repetitions completed with an absolute load. Similar to our findings, the p1RM derived from these prediction equations had a near-perfect relationship ($r = 0.99$) with measured 1RM but also had high prediction errors (27). A major disadvantage to performing repetition maximums frequently is the excessive fatigue that can accumulate when multi-joint exercises are taken to muscular failure (8). This approach seems impractical because the metric used to monitor preparedness may be in fact leading to greater amounts of fatigue. However, measuring MCV during warm-up sets offers a nonfatiguing approach. Because both methods result in similar correlations to measured 1RM and prediction errors, it is suggested that the velocity p1RM would be a superior choice for monitoring preparedness. Although this method may be used to monitor fatigue and recovery, it should not replace an actual 1RM used for prescribing training loads. More research is needed to examine the utility of velocity p1RM to autoregulate resistance exercise within a periodized training plan.

The present study consisted of male powerlifters, and therefore, the results of this study should not be extrapolated to recreationally trained, untrained populations, or female subjects. Although competitive powerlifters train with the intention of increasing maximal strength, training methods may vary. Even when following a periodized training plan, different training phases produce different physiological adaptations. Thus, previous training can influence the adaptation that occurs from the subsequent training. A limitation of the present study is that the subjects' previous training methods and recovery status were not determined before study commencement, which may have resulted in the large variation of individual responses during velocity and strength testing. However, it must be noted that during the screening process, subjects were excluded if they had competed in a powerlifting competition or peaking program 4 weeks before study commencement. Another limitation is that the results of this study are only applicable to the free-weight bench press. Future investigations are warranted to determine the effect of intensified resistance training on repetition velocity in multi-joint lower-body exercises.

In conclusion, the MCV of bench press LVPs were significantly lower after an overload microcycle and increases back to baseline after a taper. The high levels of exertion and decreased perceived recovery during the overload microcycle had small, non-significant decrease on bench press 1RM. However, after the taper, bench press 1RM supercompensated above PostOL and had a small, non-significant increase above BL. Based on the Bland-Altman analysis, the measured 1RM and p1RM had poor agreement across each microcycle, where p1RM consistently overestimated 1RM. Although velocity p1RM should not be used to prescribe training loads, the near-perfect correlation with measured 1RM suggests that velocity p1RM may be used as a tool for monitoring fatigue and adaptation to training. Future studies

should investigate this method of autoregulatory resistance exercise within a periodized training plan.

Practical Applications

Velocity monitoring is a noninvasive way to objectively assess resistance exercise performance. The current study demonstrated that bench press MCV was negatively impacted by an intensified week of resistance training in which high levels of perceived fatigue were reported. Therefore, coaches and athletes can use the MCV of warm-up sets recorded at the beginning of a training session to monitor fatigue and recovery from resistance training. Because of daily fluctuations in MCV, coaches and athletes should consider calculating the SMD to determine meaningful changes in MCV to autoregulate training. Furthermore, a pIRM derived from the MCV of warm-up sets can be calculated and used to monitor fatigue and adaptation across a training plan. Once a baseline pIRM is established, a pIRM can be recorded each week, or multiple times per week, during an athlete's warm-up sets. If pIRM declines and remains suppressed when compared with baseline values, this would indicate a fatigue, and coaches may consider adjusting training loads to allow for improved recovery. Similarly, if pIRM increases and remains elevated above baseline values, this would suggest that the athlete is responding favorably to training and that measured IRM has likely increased.

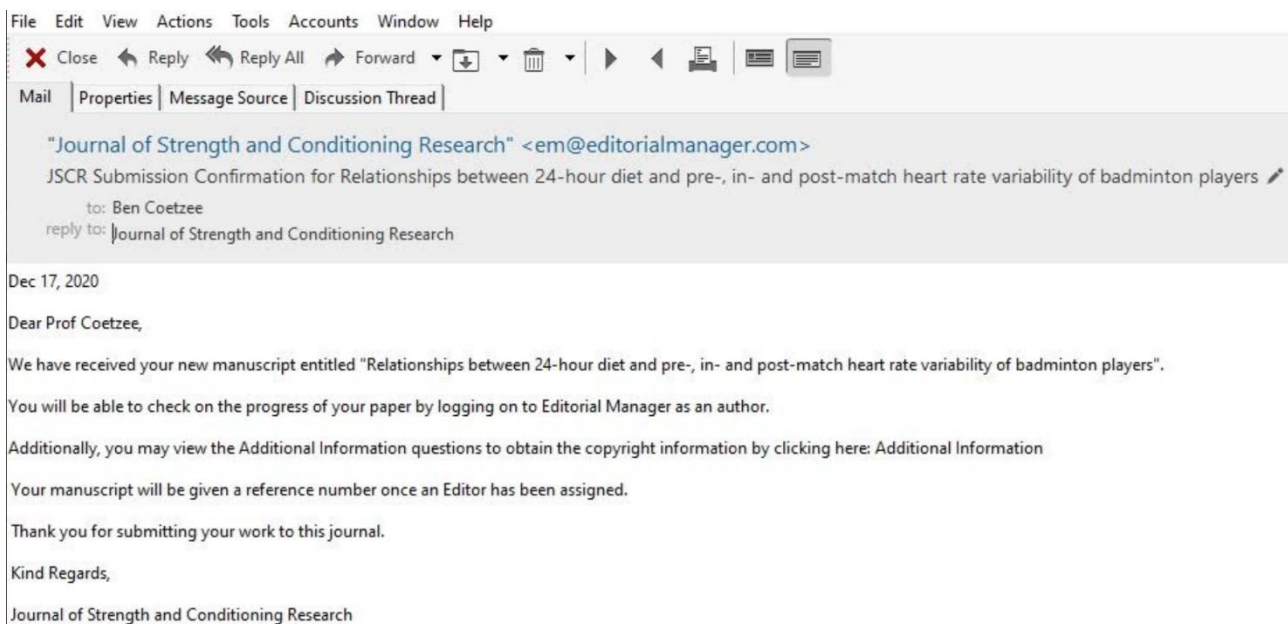
Acknowledgments

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APPENDIX K: PROOF OF ARTICLE SUBMISSION TO JOURNAL OF STRENGTH AND CONDITIONING RESEARCH



APPENDIX L: INSTRUCTIONS FOR AUTHORS OF THE INTERNATIONAL JOURNAL OF SPORTS MEDICINE

Instructions for Authors

Scope of the Journal

The *International Journal of Sports Medicine* (IJSM) provides a forum for the publication of papers dealing with basic or applied information that will advance the field of sports medicine and exercise science and offer a better understanding of biomedicine. The following sections define the scope of the journal: Training & Testing; Orthopedics & Biomechanics; Clinical Sciences; Nutrition; Behavioural Sciences; Physiology & Biochemistry; Genetics & Molecular Biology.

General Policy

The journal publishes original papers, reviews, and letters to the editor. Manuscripts submitted to the journal must contain novel data on theoretical or experimental research or on practical applications in the field of sports medicine and exercise science. Purely descriptive studies that lack generalizability to the wider world of sports medicine will be assigned a low priority and may not be entered by a corresponding editor into the peer-review process. Intervention studies which lack a comparator group and/or are very inconsistent with the CONSORT guidelines may also be assigned a low priority and not entered for peer review. Studies that employ data analysis approaches that are obviously inappropriate will also be assigned a low priority and not entered for peer-review, as will studies in which the clinical/practical significance of the findings has not been quantified and/or communicated. The paper must also be written in grammatically correct English, otherwise it may be refused for review. No substantial part of the submission should have been published elsewhere. If a part of the submission has been published or presented at a congress, symposium, national meeting proceeding or master's or doctoral theses, the reference for that publication and/or presentation should be given in the manuscript acknowledgement section. Submitted papers undergo peer reviewing by two independent reviewers. Authors may suggest names and full addresses including telephone and FAX numbers of two reviewers but not from their own institution.

Authors are required to conduct their research ethically according to international standards and as required by the journal as described in Harriss DJ, Macsween A, Atkinson, G. Standards for Ethics in Sport and Exercise Science Research: 2018 Update. *Int J Sports Med* 2017; 38: 1126-1131 (<https://www.thieme-connect.com/products/ejournals/pdf/10.1055/s-0043-124001.pdf>). Authors are expected to clearly state in the Methods section – by citing the aforementioned publication – that the study meets the ethical standards of the journal.

Categories of articles accepted for review

Original articles: Theoretical or experimental (basic or applied) research or practical applications. Either original work or the replication of work that better establishes basic principles will be considered. Original articles should not exceed a total of 15 000 characters, excluding references.

Review articles: Review articles on topics of broad interest are desirable. Authors who wish to submit an unsolicited review article should correspond with the editors-in-chief to determine the timeliness of the proposed review article. The correspondence should include an abstract and a complete outline of the proposed review article, including figures and tables (if possible). Review articles should not exceed 30 000 characters, excluding references. Review articles are considered by the editors and expert reviewers before a final decision regarding publication is made.

Letters to the editor are welcome and will be published if appropriate. Letters (maximum length 700 words) relating to material previously published in IJSM should be submitted within 6 months after publication of the material the letter is referring to. Such letters will be sent to the corresponding author for comment within six weeks. The original letter and any reply will be published concurrently. Letters to the editor are excluded from online submission and should be sent to the editorial office at ijsm.editorialoffice@thieme.de

Submission of manuscripts

Manuscripts can be submitted exclusively via online submission at <http://mc.manuscriptcentral.com/IJSM> or via link at www.thieme.de/sportsmed. **Hard copy submission and electronic submission via email are not accepted.** See below under "Uploading files on submission" for further information on the online submission process. **Style:** Manuscripts may be rejected without review on the basis of poor English or lack of conformity to stated standards of style.

Title: The title should be concise but informative.

First page: Names and addresses of the authors should not appear on the first page or elsewhere in the main document. These data are entered separately in the online submission system.

Abstract: The abstract should be informative. It should be self-explanatory without reference to the text of the manuscript. It should include essential significant results that support the conclusion of the work. Three to six key words not used in the title should also be provided (these can be entered during the online submission). Abbreviations should not be used in the abstract.

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Do not exhaustively review the literature.

Materials & Methods: Provide sufficient information in the text or by reference to other work to permit the submitted work to be repeated without the need to communicate with the authors. Relevant validity and reliability data should be provided for critical methods. State the type of statistical tests used. Include the number of observations and the statistical findings when appropriate. Parametric and non-parametric statistics must be used as appropriate.

Results: Should be presented precisely and should not contain material that is appropriate in the discussion. Units, quantities, and formulas should be expressed according to the *Système Internationale* (SI units). All measurements should be given in metric units. **Discussion:** Emphasize the new and important aspects of the study and conclusions from the study.

Acknowledgements: Financial support should be stated. **References:** References should be cited in the text by number and listed in order of their citation in the paper. Authors bear complete responsibility for the accuracy of the references.

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¹ Palmer GS, Dennis SC, Noakes TD et al. Assessment of the reproducibility of performance testing on an air-braked cycle ergometer. *Int J Sports Med* 1996; 17: 293–298

Complete book:

¹ Dingle JT (ed). *Lysosomes*. New York: American Elsevier, 1972: 65

Chapter of a book:

¹ Zancetti A, Baccelli G, Guazzi M et al. The effect of sleep on experimental hypertension. In: Onesti G, Kim KE, Moyer JH (eds). *Hypertension: Mechanisms and Management*. New York: Grune & Stratton, 1973: 133–140

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Tables: Tables should be used to communicate information that is hard to present visually. Results whose interpretation is more easily comprehended by knowing the means and SEM (or SD) may be presented in a table(s). Tables should be self-explanatory and bear a short title. Table legends should be typed on the same sheet as the table as a header. A footnote to the table should explain all abbreviations used in the table. Tables should be provided either as word or excel files.

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APPENDIX M: EXAMPLE OF ARTICLE PUBLISHED IN THE INTERNATIONAL JOURNAL OF SPORTS MEDICINE

Injury Incidence Rates and Profiles in Elite Taekwondo during Competition and Training

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Key words

Taekwondo, athletic injuries, martial arts, hand injuries, ankle injuries

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ABSTRACT

This study aimed to investigate exposure-adjusted injury incidence rates and profiles associated with training and competition in an elite taekwondo athlete population. 82 athletes were investigated for injuries over a period of 5 years. Individual fight time exposure for training and competition was recorded. The type and location of the injuries were classified and exposure-adjusted injury incidence rates (IR) were calculated per 1000 h for training and competition. 66 athletes with a mean age of 19.3 ± 4.2 years and 172 injuries were included in the final data assessment. The exposure-adjusted IR was significantly higher during competition ($p < 0.001$) with a rate ratio of 6.13 (95% CI 4.58–8.65). Ankle and foot region as well as hand and wrist were most affected with significant higher IR in competition ($p < 0.001$). Joint injuries, fractures, and bruising occurred the most. Fractures occurred mainly to the hand and wrist region. Future investigations should focus on exposure-adjusted injury data including analyses of the detailed mechanism leading to especially severe injuries to improve specific injury prevention in competition and promote evaluation of protective gear.

Introduction

Taekwondo is one of the most popular practiced combat sports worldwide, combining spiritual values with the high demands of a global Olympic elite discipline [1]. Competitions in Olympic style taekwondo are characterized by full-contact, intense and dynamic fights with high frequency kicking and punching techniques. This requires substantial flexibility and endurance [2]. The goal is to score the most points or win by knockout. Scoring areas are the trunk and the head. Therefore, the focus during fights are kicking techniques with the lower limb delivering forceful blows to the opponent's trunk or head. Protective gear is mandatory in both spar-

ring and competition fights. The rules and regulations are governed by the world taekwondo federation (WTF). Competition fights consist of rounds that typically last two minutes each. To compete on an international level elite athletes train five to seven times a week including full-contact sparring fights for competition simulation [3–6]. Since injury risk in taekwondo was the highest compared to all other sports during the Olympic games 2012 there is growing interest in injury rates and prevention [3, 7–13]. The lower extremities have been reported as the main site of injuries in taekwondo of different levels before [1, 8, 9, 14]. However, there are only scarce data on injuries regarding the upper extremity [3, 9].

Individual injury rates were presented in previous studies with a wide range and only few studies were able to adjust injury rates to the individual exposure time [9, 14, 15]. There is a lack of direct comparison of exposure-adjusted training and competition injury incidence rates in taekwondo. It is a known fact that injury rates are higher during competitions compared to training. But one must consider that athletes spend a lot more time training than competing [16]. Furthermore, there is also the need to provide data on injury profiles between training and competition in martial arts [4, 9, 10, 17, 18]. This study aimed to compare exposure-adjusted injury incidence rates of training and competition in elite taekwondo athletes over a period of 5 years.

Materials and Methods

Study population and outcomes of interest

A subset of 82 elite taekwondo athletes from a single national Olympic training center with a total of 107 athletes gave their consent for this study and were therefore investigated prospectively for injury incidence rates over a study period of five years (1 January 2014 to 31 December 2018). Primary outcome of interest was the comparison of IIRs between training fights and competition fights. Secondary outcome of interest was the analysis of potential differences in injury profiles regarding the anatomical body region. All athletes took part in an institutional training schedule, (with a frequency of 5–6 times a week). During the study period competition exposure was comparable within all athletes because of the national and world taekwondo federation tournament schedule. All stars of athletes who finished their career during the study period ($n = 7$), lost their elite status ($n = 1$) or presented with incomplete exposure time or medical documentation ($n = 13$) were excluded. Complete training and competition records for the whole study period were obtained for 66 athletes. As requested by the official rules, the use of protective gear was mandatory for all athletes during training and competition fights. This was supervised by medical and training staff during training as well as by the official referees during competitions.

Data collection

Exposure time during training was assessed daily by the relevant medical staff (physician or physiotherapist), including bodyweight, duration and frequency of training fights. During competitions, bodyweight and fight time was assessed by official referees. Injuries were recorded during training and competition by the attending medical staff. In case of an injury, athletes were examined by experienced sport orthopedic specialists from an Olympic training center within the first week. The exact diagnosis of injuries was based on clinical examination as well as radiologic results from ultrasound, X-ray and MRI data. Only acute injuries which occurred during a training or competition fight were included in the study. In the case of injury, data collection restarted only when the athlete fully recovered – confirmed by an experienced sport orthopedic specialist.

Operational definitions

We defined injuries according to the criteria recommended by Junge, Engebretsen et al. [7, 19]: “We defined injuries and illnesses as new or

recurring injuries or illnesses receiving medical attention, regardless of the consequences with respect to absence from competition or training.” For classification of injuries the widely used Orchard Sports Injury Classification System 10 (OSICS 10) was used [20].

Statistical analysis

Data about fight exposure and injuries were recorded prospectively. As the number of elite athletes is limited by nature, no sample size was calculated. As published before, the calculation of injury incidence rates (IR) was calculated with the athlete’s exposure per 1000 h of training fight time or per 1000 h of competition fight time with 95 % confidence intervals, respectively:

$$IR = \frac{\text{number of injuries}}{\text{number of hours of exposure}} \times 1000 \text{ h}$$

Furthermore, rate ratios were determined by dividing the IR of competition by the IR of training fights. For body regions with zero count rates (offense and lower leg) rate ratios are not reported. Calculation of training and competition injury incidence rates and risk ratios were calculated with 95 % confidence intervals (for Poisson rates). For comparison of injury incidence rates the exact Poisson test was used. All reported p -values are two-tailed. They were considered significant in case of an alpha level $p < 0.05$. Descriptive results are demonstrated as mean $\pm$ standard deviation as well as the range. Statistical analysis was performed using “R” statistic software (version 3.5.1). The study protocol was approved by the competent research ethics board. All participants gave their informed consent to the study. We confirm that the study meets the ICMJE ethical standards as described by Burke et al. [31].

Results

66 participants (29 females and 37 males) were included in the study with a mean age of 19.3 ± 4.2 years. The gender distribution of athletes showed no relevant differences between male and fe-

Table 1 Characteristics of participants

	Total	Male	Female
Number of athletes, n (%)			
Overall	66 (100)	37 (56)	29 (44)
Body weight ≤ 50 kg	12 (18)	5 (13)	7 (24)
Body weight > 50 –60kg	25 (38)	15 (41)	10 (34)
Body weight > 60 –70kg	16 (24)	8 (22)	8 (28)
Body weight > 70 kg	13 (20)	9 (24)	4 (14)
Age in years, mean $\pm$ SD (range)			
Overall	19.3 $\pm$ 4.2 (14–32)	19.8 $\pm$ 4.5 (14–32)	18.7 $\pm$ 3.7 (14–28)
Body weight ≤ 50 kg	15.7 $\pm$ 1.8 (14–17)	16 $\pm$ 0.9 (14–17)	15.2 $\pm$ 0.7 (14–16)
Body weight > 50 –60kg	18.8 $\pm$ 4.8 (14–32)	18.2 $\pm$ 3.3 (14–32)	18.9 $\pm$ 4.3 (15–32)
Body weight > 60 –70kg	19.9 $\pm$ 3.8 (14–30)	19.5 $\pm$ 2.2 (16–30)	20.5 $\pm$ 4.4 (14–30)
Body weight > 70 kg	23.4 $\pm$ 3.6 (17–29)	23.25 $\pm$ 4.9 (17–28)	23.6 $\pm$ 2.7 (19–29)

male athletes ($n = \text{Table 1}$). The mean exposure time per athlete was 107.1 ± 27.7 h (range 65.0–195.0) for training and 10.5 ± 2.7 h (range 6.0–16.8) for competition.

A total of 172 injuries were recorded, of which 106 (62%) occurred during training and 66 (38%) during competition. 61% of all injuries to the lower extremities ($n = 97$) occurred during training and 39% during competition. On the upper extremity 58% of all injuries ($n = 57$) were recorded during training and 42% during competition. Overall the most affected body region in training and competition was the hand and wrist (17%) followed by the foot (16%) and ankle (13%). Frequencies and proportions of injury sites are demonstrated in $\Rightarrow \text{Table 2}$.

The mean injury incidence rate (IR) was 94.98 (73.45–120.84 CI 95%) for competition and 15.00 (12.28–18.14 CI 95%) for training with a 6.33-fold increased risk for injury during competition. The highest IR was found for the categories hand & wrist and the ankle joint during competition with 30.22 (18.71–46.20 CI 95%) and 18.71 (9.96–31.99 CI 95%), respectively. IR for training and competition fights as well as the rate ratio and statistical analysis are presented in $\Rightarrow \text{Table 3}$. Exposure-adjusted injury rate ratio was 7.40 for the upper and 6.55 for the lower extremity. Highest injury

rate ratio was found for the thigh region (35.5) followed by the ankle joint (14.69).

Regarding the locations “elbow” and “lower leg” no injuries occurred during competition. Therefore, the statistical analysis is not meaningful ($p = 1$). Furthermore, the number of shoulder injuries was in fact high enough to calculate a p -value, but too low to receive a reliable confidence interval.

Comparing the injury patterns according to OISICS for both training and competition fights, joint injuries ($n = 52$), fractures ($n = 37$) and bruising ($n = 28$) occurred the most. Frequencies and proportions of injury patterns are demonstrated in $\Rightarrow \text{Table 4}$.

Discussion

The main finding of this study is that taekwondo athletes show a 6.33-fold increased rate for injuries during competition compared to training when adjusted to exposure time. Significant higher IR were especially found for the hand and wrist region on the upper extremity and for the hip, thigh, knee and ankle joint region on the lower extremity.

$\Rightarrow \text{Table 2}$ Frequencies and proportions of injury sites during competition and training

Body region	Training	Competition	Proportions of injuries (training/competition)
Shoulder	2	3	0.60
Elbow	1	0	–
Wrist & hand	20	11	1.85
Hip & groin	0	5	1.5
Thigh	2	7	0.29
Knee	14	8	1.75
Lower leg	3	0	–
Ankle	9	18	0.25
Foot	23	5	4.6
Other	14	4	–
Total	106	66	1.60

$\Rightarrow \text{Table 4}$ Frequencies and proportions of injury patterns during competition and training

Type of injury	Training	Competition	Proportion of injuries (training/competition)
Cartilage injury	4	4	1
Joint injury	25	12	2.1
Fracture	12	15	1.4
Dislocation	5	3	2.5
Fracture injury	5	6	0.8
Muscle injury	5	8	0.6
Bruising	18	10	1.8
Stress injury	1	0	–
Lacerations	8	2	4
Synovitis	3	0	–
Concussion	0	2	–
Total	106	66	1.6

$\Rightarrow \text{Table 5}$ Injury incidence rates and exposure-adjusted injury rate ratios for competition and training

Location	Injury incidence rate per 1000 h of participation in competitions (CI 95 %)	Injury incidence rate per 1000 h of training (CI 95 %)	Exposure-adjusted injury rate ratio (CI 95 %)	p , two-tailed
All locations	94.98 (73.45–120.84)	15.00 (12.28–18.14)	6.33 (4.58–8.89)	<0.001
Upper extremity	34.34 (22.15–51.39)	4.67 (3.21–6.56)	7.40 (4.18–12.90)	<0.001
Shoulder	4.32 (0.89–12.62)	0.28 (0.03–1.02)	15.25 (1.75–182.64)	0.012
Elbow	0.00 (0.00–5.51)	0.14 (0.00–0.79)	–	1.00
Hand and Wrist	30.22 (18.71–46.20)	4.25 (2.86–6.06)	7.12 (3.87–12.86)	<0.001
Lower Extremity	54.68 (38.70–75.86)	8.33 (6.38–10.77)	6.55 (4.24–10.01)	<0.001
Hip	7.20 (2.34–16.78)	1.13 (0.49–2.22)	6.36 (1.64–22.04)	0.008
Thigh	10.07 (4.05–20.76)	0.28 (0.03–1.02)	35.59 (6.78–191.17)	<0.001
Knee	11.31 (4.97–22.88)	1.98 (1.08–3.52)	5.81 (2.11–14.84)	<0.001
Lower leg	0.00 (0.00–5.21)	0.42 (0.00–1.24)	–	1.00
Ankle joint	18.71 (9.98–31.99)	1.27 (0.58–2.83)	14.69 (5.81–38.94)	<0.001
Foot	7.20 (2.34–16.78)	3.25 (2.06–4.88)	2.21 (0.66–5.95)	0.208

Previous studies described overall injury rates with an exposure being defined as one training or one competition session, but they did not provide an adjusted exposure risk for training and competition separately [1, 5, 6, 14, 21–23]. In a meta-analysis of competition taekwondo injuries, Iystrand et al. found a wide range of total IR between 20.5 and 181.8 analyzing nine studies on different sub-groups of taekwondo athletes [10]. Pieter et al. reviewed five prospective studies on adult elite athletes and demonstrated IRs between 28.6–139.5 for males and 25.3–105.5 for females without providing fight time adjusted exposure time [7]. Investigation of injuries for amateur and elite athletes found a lower exposure adjusted IR of 59.9–69.5 and 16.3–21.3 but did not provide clear definition of injuries nor explicit data on training injuries [9, 24]. In the present study a total IR of 64.68 for competition could be found. The significant higher IR in competition compared to training might be explained due to a more aggressive fight style of the elite athletes during competition. The higher impact and amount of strikes in competitions may contribute to the rise in injuries. It is also likely that during training fights elite athletes might be more concentrated on performing correct fighting techniques while being under supervision by coaches.

In a recent study by Park et al. the injury patterns associated with elite taekwondo training was analyzed prospectively over a 16-year period [6]. In this regard, most injuries affected the lower extremities (55.7%). Previous studies have also found the lower limb – especially the foot – to be the most injured region with significant differences regarding sex and weight class [7, 8, 9]. In contrast, hand injuries only accounted for 6% of all injuries in an exemplified study [3]. But so far, no differentiation between training and competition injuries was made in those studies. Our data support the finding that lower limb injuries are the most frequent with an IR of 64.68 in competition with significant higher IR for injuries to the thigh, knee and ankle joint. But our data also show a significant higher IR of 34.94 in competition for the upper extremity. We could even demonstrate a slightly higher rate for the upper extremity (7.40) compared to the lower extremity (6.55). Analysis of injury rates on the upper extremity in competition to exact anatomical location demonstrated a significant higher IR for the hand and wrist region. Those injuries also included the vast majority of fractures, dislocations and joint injuries in our study. Until now, only two studies could show a higher proportion of moderate-to-severe injuries relative to other body regions for the upper limb in competition fights [9, 13]. Higher weight class and lacking blocking skills have been described as risk factors in past studies [17, 25]. Individual technical skills might therefore play an important role. While the lower limb is the main body part used for attacking kicks to the opponents' head and body, the upper extremity is often used for blocking. With increasing aggression in elite competitions it can be supposed that the numerous found injuries to the foot and ankle are mainly caused by the powerful attacks delivered through frequent kicking. Especially technical demanding turning kicks display high acceleration force and may cause injury to the attackers' foot and ankle. Furthermore, during the explosive eccentric muscle contractions the thigh becomes prone to muscle injuries. The correct training and performance of kicks with avoidance of hitting the opponents unprotected knee or elbow might reduce those injuries.

But there is also some evidence that in taekwondo protective gear mainly protects the attacker rather than the defender [5]. Assuming that hand injuries are associated with poorly performed blocking skills it is likely that those injuries occur within competition fights when physic and physiological stress reach a maximum level [2, 26].

Despite the mandatory use of protective hand gear in both training and competition this study underlines that relying on gear alone cannot prevent severe injuries caused by excessive forces deriving from attacking punches and blocking of foot kicks [25, 27–29]. To prevent ongoing rise in injuries in Olympic taekwondo athletes coaches should put emphasis on technical skills even under physiological and psychological stress during training as recommended before [30]. Further analysis of detailed injury patterns should differ between attack or defensive movements for improvement of protective gear and skills in this sport.

Study limitations

Despite the prospective study design, a certain selection bias can be assumed as only a small number of elite athletes from a single training center were included in the study. Furthermore, a bias in exposure data occurred due to athletes lost at follow up. Successful athletes have higher competition exposure time compared to less successful ones, which might have dropped out early. It remains unclear in this study if injury risk stayed constant for the remaining 66 athletes over time. Due to the nature of the sport training fight time equals competition fight time which leads to a certain imbalance in individual exposure. Time lost from participation due to injury might also have acted as a confounding factor. Furthermore, some injuries might not have been recorded because of an underestimation by the athlete which lead to an information bias during data collection. The limited amount of reported concussion or head striking injuries in contrast to the large amount of fractures and joint injuries reported in the study might indicate this bias. Finally, observer bias could have also occurred since information on injuries was reported by different competition occupational groups.

Conclusion

Taekwondo athletes show a 6.35-fold increased rate for injuries during competition compared to training when adjusted to exposure time. Therefore, future investigations should provide exposure adjusted injury data with focus on the detailed mechanism to improve specific injury prevention in competition and promote evolution of protective gear. Level of evidence: Level II: prospective single-group cohort observational study.

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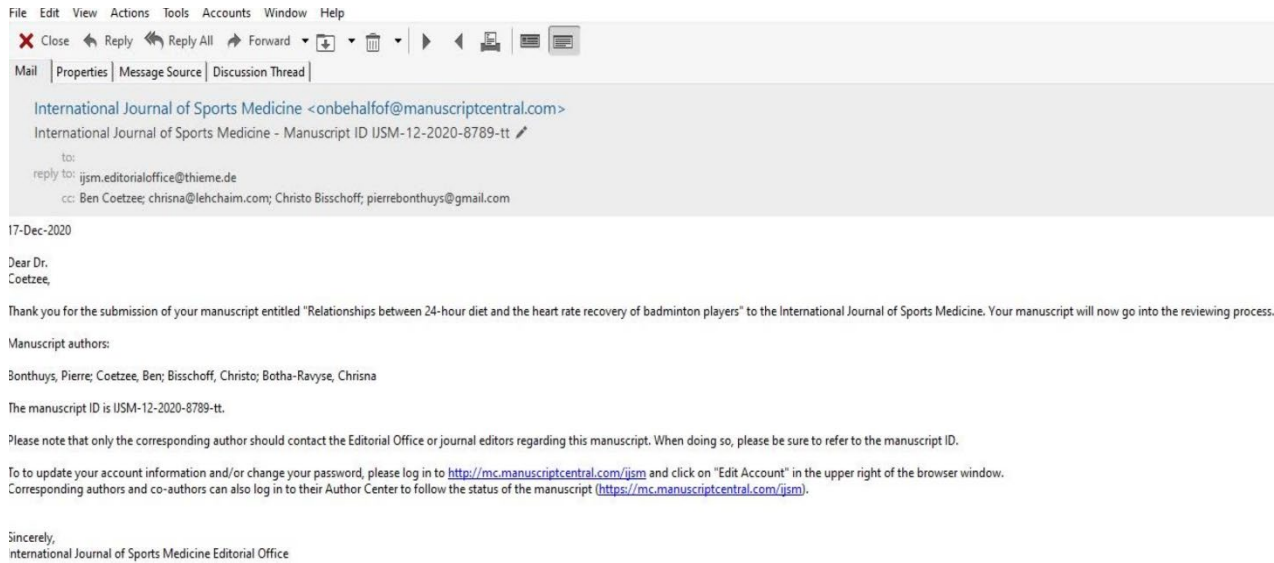
Conflict of Interest

The authors declare that they have no conflict of interest.

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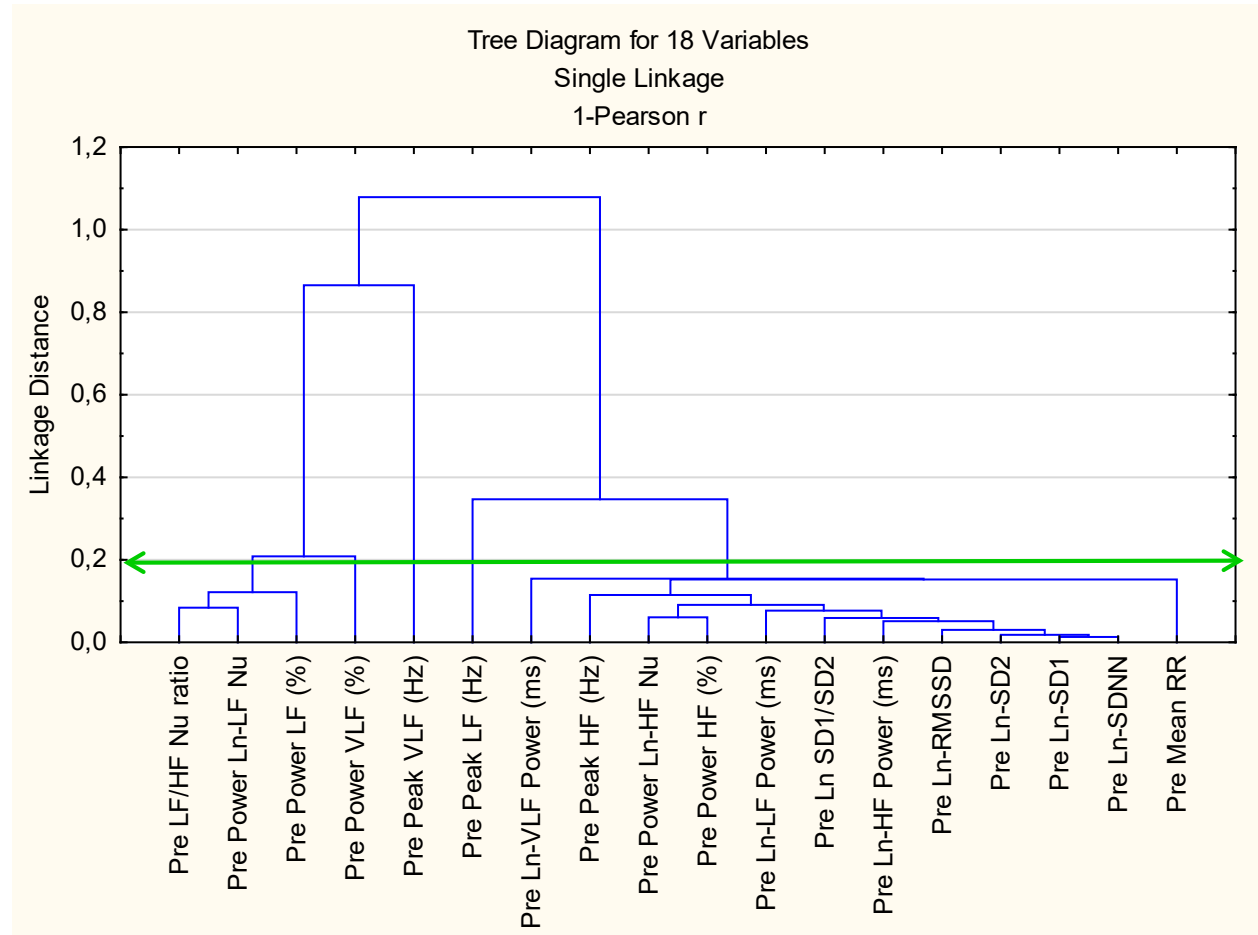
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APPENDIX N: PROOF OF ARTICLE SUBMISSION TO INTERNATIONAL JOURNAL OF SPORTS MEDICINE

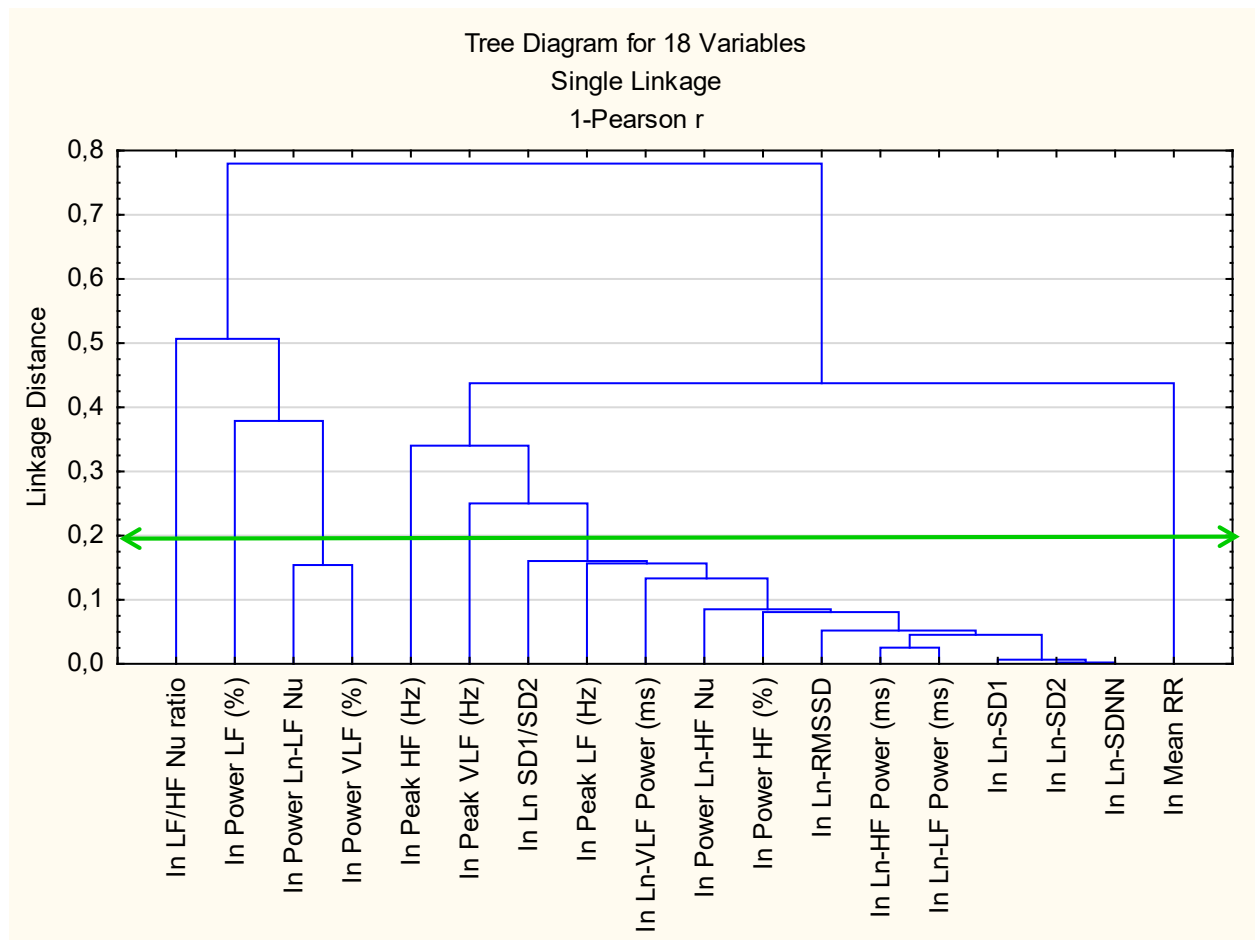


APPENDIX O: SINGLE-LINKAGE, TREE CLUSTER (1-PEARSON CORRELATION COEFFICIENT) ANALYSIS RESULTS OF HRV, HRR VARIABLES FOR ALL PERIODS OF THE MATCHES (CHAPTER 3 AND 4)

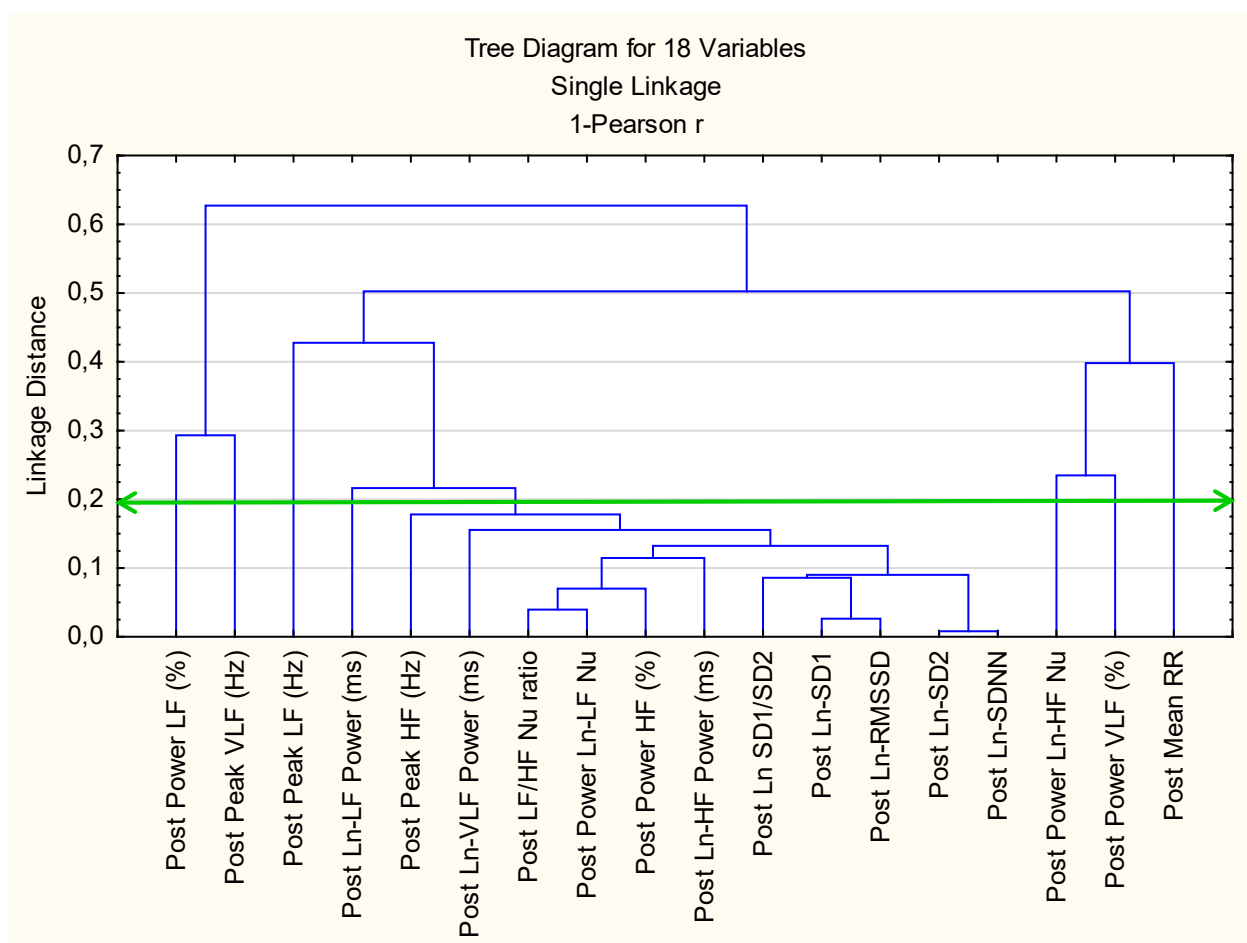
Before Match (Pre-Match)



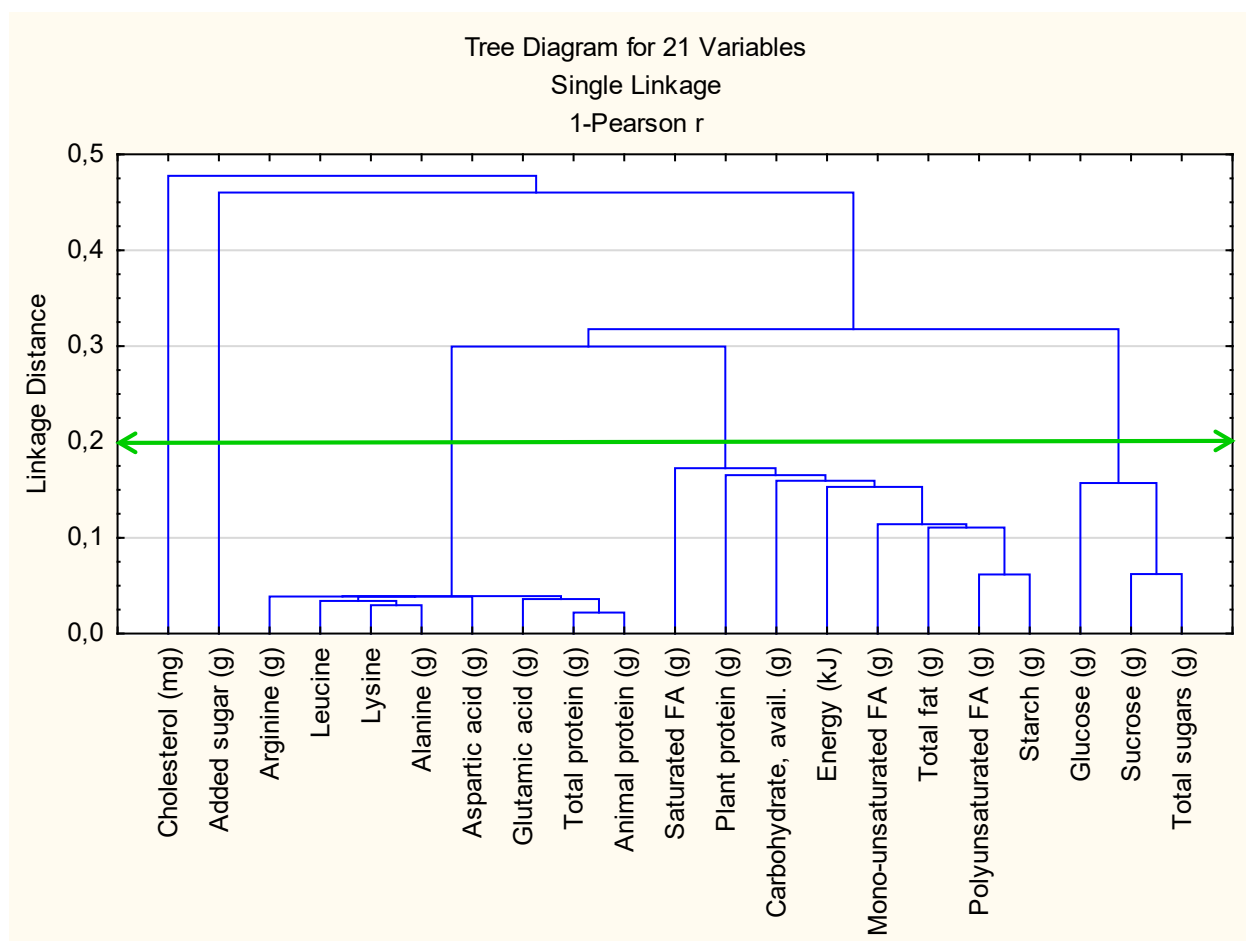
During Match (In-Match)



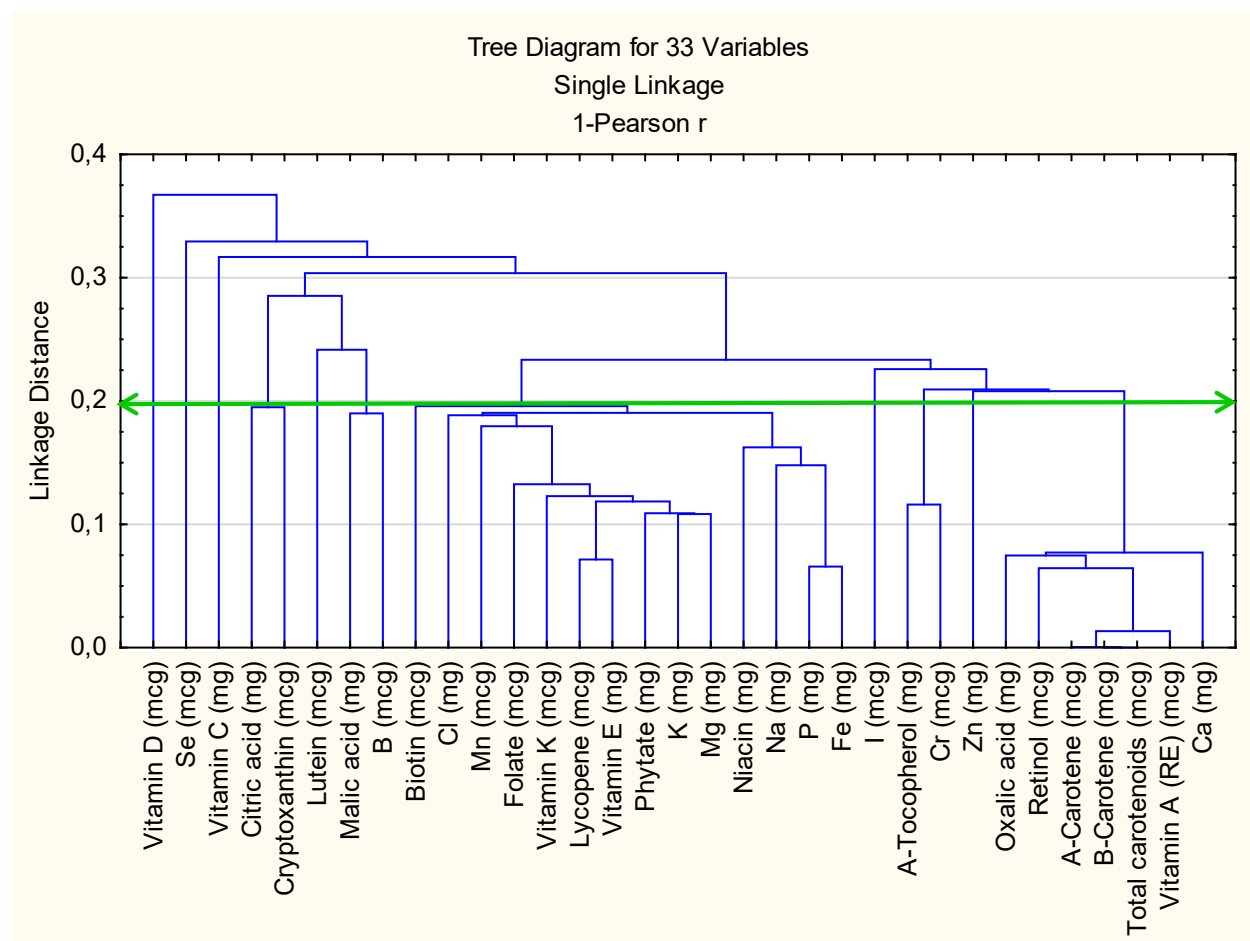
After Match (Post-Match)



APPENDIX P: SINGLE-LINKAGE, TREE CLUSTER (1-PEARSON CORRELATION COEFFICIENT) ANALYSIS RESULTS OF MACRONUTRIENTS (CHAPTER 3 AND 4)



APPENDIX Q: SINGLE-LINKAGE, TREE CLUSTER (1-PEARSON CORRELATION COEFFICIENT) ANALYSIS RESULTS OF MICRONUTRIENTS (CHAPTER 3 AND 4)



APPENDIX R: CHAPTER 3 AND 4: CANONICAL LOADINGS

CHAPTER 3: CANONICAL LOADINGS OF THE HRV-, MACRO- AND MICRONUTRIENT-RELATED VARIABLES

Canonical loadings of the HRV-related variables for the pre-match period

HRV variable	Canonical loading
Ln-RMSSD	-0.452
Peak VLF (Hz)	0.879
Peak LF (Hz)	-0.589
Power VLF (%)	0.487
Power Ln-LF Nu	0.323
Ln-RMSSD	0.973
Peak VLF (Hz)	-0.295
Peak LF (Hz)	0.554
Power VLF (%)	-0.602
Power Ln-LF Nu	-0.800

Canonical loadings of the HRV-related variables for the in-match period

HRV variable	Canonical loading
Mean RR	-0.137
Ln-RMSSD	-0.864
Peak VLF (Hz)	-0.449
Peak LF (Hz)	-0.839
Peak HF (Hz)	0.042
Power LF (%)	0.074
Power Ln-LF Nu	0.610
LF/HF Nu ratio	0.409
Mean RR	0.332
Ln-RMSSD	-0.483
Peak VLF (Hz)	-0.922
Peak LF (Hz)	-0.345
Peak HF (Hz)	-0.267
Power LF (%)	-0.137
Power Ln-LF Nu	0.497
LF/HF Nu ratio	0.014

Canonical loadings of the HRV-related variables for the post-match period

HRV variable	Canonical loading
Mean RR	0.165
Ln-RMSSD	-0.915
Peak VLF (Hz)	0.727
Peak LF (Hz)	-0.056
Ln-LF Power (ms)	-0.681
Power VLF (%)	0.200
Power LF (%)	0.357
Power Ln-LF Nu	-0.611
Mean RR	0.614
Ln-RMSSD	0.147
Peak VLF (Hz)	-0.036
Peak LF (Hz)	0.194
Ln-LF Power (ms)	0.605
Power VLF (%)	-0.233
Power LF (%)	0.036
Power Ln-LF Nu	0.386

Canonical loadings of the macronutrient-related variables for the pre-match period

Macronutrient-related variables	Canonical loading
Total protein (g)	0.270
Total trans FA (g)	0.651
Cholesterol (mg)	0.168
Carbohydrate, availability. (g)	0.472
Lactose (g)	-0.247
Total sugars (g)	0.349
Added sugar (g)	-0.158

Canonical loadings of the macronutrient-related variables for the in-match period

Macronutrient-related variables	Canonical loading
Total protein (g)	-0.168
Total trans FA (g)	-0.940
Cholesterol (mg)	-0.028
Carbohydrate, availability (g)	0.449
Lactose (g)	-0.102
Total sugars (g)	0.307
Added sugar (g)	0.712

Canonical loadings of the macronutrient-related variables for the post-match period

Macronutrient-related variables	Canonical loading
Total protein (g)	-0.112
Total trans FA (g)	-0.835
Cholesterol (mg)	0.122
Carbohydrate, avail. (g)	0.518
Lactose (g)	-0.286
Total sugars (g)	0.413
Added sugar (g)	0.662

Canonical loadings of the micronutrient-related variables for the pre-match period

Micronutrient-related variables	Canonical loading
Ca (mg)	-0.512
K (mg)	-0.502
Zn (mg)	-0.114
Cr (mcg)	0.128
Se (mcg)	0.015
I (mcg)	-0.143
B (mcg)	-0.350
Vitamin C (mg)	0.021
Vitamin D (mcg)	0.445
Citric acid (mg)	-0.171
Lutein (mcg)	-0.052

Canonical loadings of the micronutrient-related variables for the in-match period

Micronutrient-related variables	Canonical loading
Ca (mg)	-0.348
K (mg)	-0.041
Zn (mg)	-0.033
Cr (mcg)	0.222
Se (mcg)	0.269
I (mcg)	0.069
B (mcg)	0.139
Vitamin C (mg)	0.228
Vitamin D (mcg)	0.291
Citric acid (mg)	0.144
Lutein (mcg)	0.188

Canonical loadings of the micronutrient-related variables for the post-match period

Micronutrient-related variables	Canonical loading
Ca (mg)	0.127
K (mg)	-0.348
Zn (mg)	0.182
Cr (mcg)	-0.047
Se (mcg)	0.159
I (mcg)	-0.029
B (mcg)	-0.003
Vitamin C (mg)	-0.076
Vitamin D (mcg)	0.217
Citric acid (mg)	-0.198
Lutein (mcg)	-0.171

CHAPTER 4: CANONICAL LOADINGS OF THE MACRO- AND MICRONUTRIENT-RELATED VARIABLES

Canonical loadings of the macronutrient-related variables

Macronutrient-related variables	Canonical loading
Total protein (g)	0.287
Total trans FA (g)	-0.555
Cholesterol (mg)	-0.237
Carbohydrate, availability (g)	0.925
Added sugar (g)	0.494
Total sugars (g)	0.651
Lactose (g)	0.278

Canonical loadings of the micronutrient-related variables

Micronutrient-related variables	Canonical loading
Ca (mg)	0.410
K (mg)	0.398
Zn (mg)	-0.043
Cr (mcg)	-0.274
Se (mcg)	-0.092
I (mcg)	-0.049
B (mcg)	0.228
Vitamin C (mg)	0.271
Vitamin D (mcg)	-0.588

APPENDIX S: LETTER FROM LANGUAGE EDITOR



EDITING CERTIFICATE

16 December 2020

To whom it may concern

DECLARATION OF LANGUAGE EDITING

Re: Relationships between 24-hour diet and autonomic markers of heart rate in badminton players.

This serves to confirm that I, Tanya-Lee Ruby Stewart, a SATI-registered language editor and translator, undertook the language editing of the above-mentioned document on behalf of Mr P Bonthuys, NWU student number: 24003247, for the purpose of meeting the submission requirements of an M degree.

Do note: changes and corrections were suggested by means of “track changes” and e-mails. However, the implementation thereof was left up to the author.

Should you have any queries, please contact me through the email address and telephone number provided by the letterhead.

Yours sincerely

TR Stewart
Member: South African Translators'
Institute SATI registration no: 1003470

