Internal and external match loads of university-level soccer players: a comparison between methods

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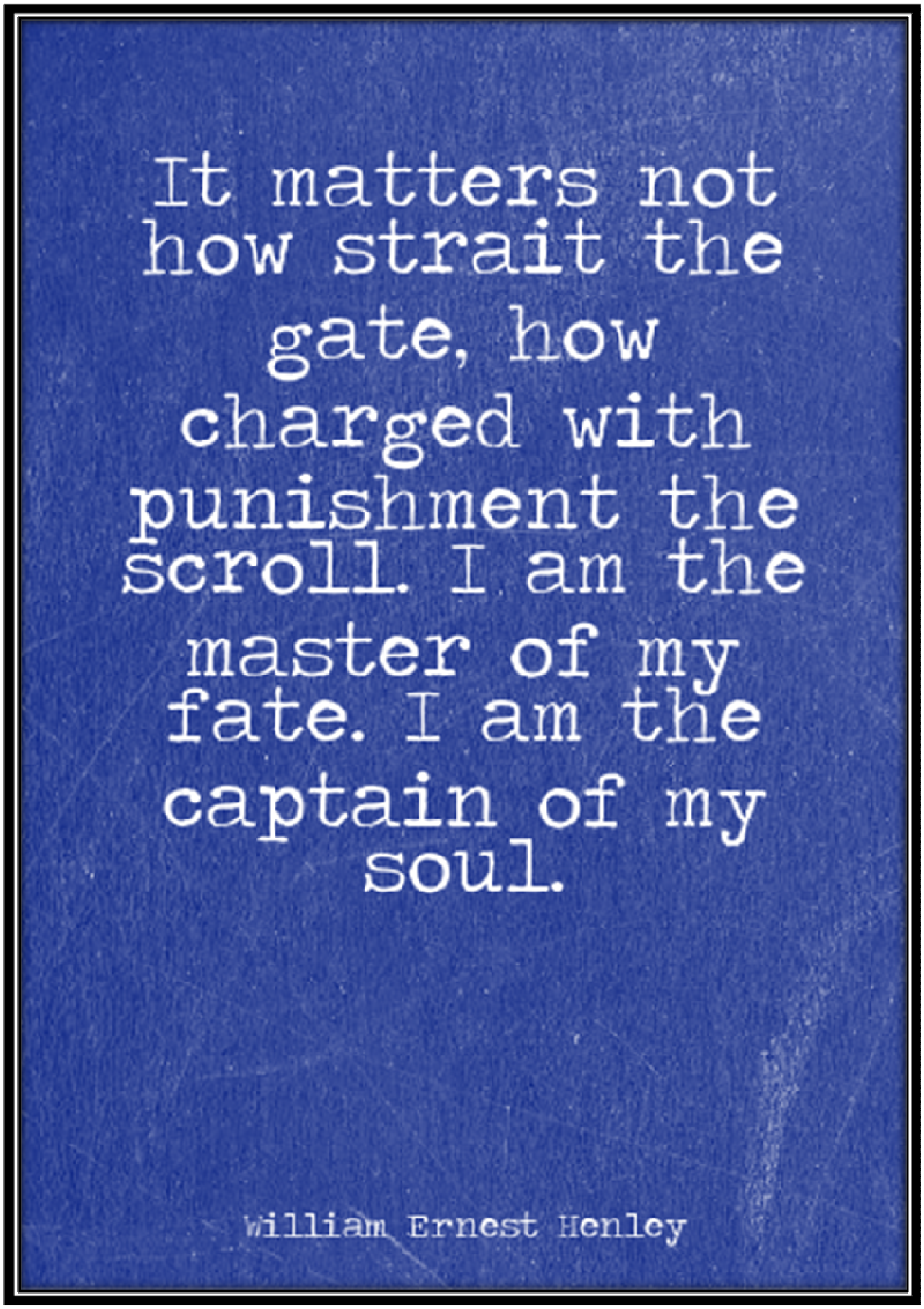
It matters not how strait the gate, how charged with punishment the scroll. I am the master of my fate. I am the captain of my soul.
William Ernest Henley

DECLARATION

The principle author of this thesis is Ms. M. Sparks. The contribution of each of the co-authors involved in this study is summarized in the following table:

Author	**Contribution**
Ms. M. Sparks	Author. Conceptualizing of project. Design and planning of manuscripts, compilation and execution of relevant testing procedures, literature review, data extraction, writing of manuscripts, interpretation of results.
Co-authors	**Contribution**
Assoc. Prof. B. Coetzee	Promoter. Co-reviewer, assistance in planning and writing of manuscripts as well as interpretation of results. Critical review of contents, including the Thesis and Articles 1, 2 and 3
Assoc. Prof. T.J. Gabbett	Co-Promoter. Co-reviewer, assistance in planning and writing of manuscripts as well as interpretation of results. Critical review of contents, including the Thesis and Articles 1, 2 and 3

The following is a statement from the co-authors confirming their individual role in each study and giving their permission that the manuscripts may form part of this thesis.

I declare that I have approved the above mentioned manuscripts, that my role in the study, as indicated above, is representative of my actual contribution and that I hereby give my consent that they may be published as part of the Ph.D. thesis of Martinique Sparks.

Assoc. Prof. B. Coetzee

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SUMMARY

INTERNAL AND EXTERNAL MATCH LOADS OF UNIVERSITY-LEVEL SOCCER PLAYERS: A COMPARISON BETWEEN METHODS

A need exists to obtain accurate, reliable and valid data to assess the external and internal loads of soccer matches, especially as it relates to South African soccer teams. Consequently, the objectives of this study were firstly to determine the fatigue rates and patterns of a cohort of university-level soccer players during matches when using global positioning system (GPS) to quantify the high-intensity running performances in rolling 5-min periods. Secondly, to determine the influence of Yo-Yo intermittent recovery test level 1 (Yo-Yo IR1) determined training status of a cohort of university-level soccer players on fatigue patterns and rate during match play. Thirdly, to determine the positional-internal match loads of a cohort of university-level soccer players by making use of heart rates and the Yo-Yo IR1-determined threshold values. Lastly, to compare the match analysis results of different methods aimed at determining the external and internal match loads of a cohort of university-level soccer players.

Selected groups of university-level soccer players (n = 10–13) were required to complete a 40-m maximum speed test and the Yo-Yo IR1 during a two-week period either before or after each analysed match. The heart rate (HR) values and GPS data of each player were recorded during league soccer matches.

For the first and second objectives of the study players were categorised into three activity level categories (low, moderate and high) according to their activity levels of the first half of the match. Furthermore, their high-intensity running (> 3.7m/s) (HIR) was monitored in rolling 5-min periods. The low-activity group showed a small to moderate difference ($p < 0.05$) in high-intensity running (HIR) at 5-min and 15-min after the peak period compared to the average 5-min period. The moderate-activity group showed a moderate difference ($p < 0.05$) in HIR at 5-min after the peak period. The high-activity group showed moderate to large declines in distance covered between the first 15-min of the second half (103.9 m/min) compared to the first 15-min of the first half (122.5 m/min). They also showed small to moderate declines in HIR during the first 10-min of the second half (25.7 m/min) compared to the first half (34.1 m/min). The low-activity group showed a small decline in distance covered during the first 5-min of the second half (76.3 m/min) compared to the first half (87.7

m/min). Conversely the low-activity group showed a small to moderate increase in distance covered during the last 10-min of the second half (95.7 m/min) compared to the first half (84.4 m/min). The Yo-Yo IR1 was not significantly correlated with any of the variables associated with HIR.

For the third objective of the study players' heart rates that corresponded with the first and second ventilatory thresholds as obtained during a Yo-Yo IR1 were used to classify heart rates into low (LI HR zone), moderate (MI HR zone) and high-intensity zones (HI HR zone). Results showed that attackers spent more time in the LI HR zone (3386 s; 62%; $p < 0.05$) than defenders (2155 s; 40%) and midfielders (2425 s; 42%). The attackers spent less time in the HI HR zone (260 s; 4%; $p < 0.05$) than the defenders (964 s; 15%). Midfielders (2444 s; 44%) and defenders (2364 s; 41%) spent more time in the MI HR zone than attackers (1854 s; 44%).

For the fourth objective of the study players' individualised velocity and heart rate (HR) thresholds were determined from the 40-m maximum speed test and the Yo-Yo IR1. Results showed a large ($r = 0.5$; $p \leq 0.01$) correlation between the time spent in the LIVZ (5017 ± 368 s) and the LI HR zone (2891 ± 1086 s), with the true correlation value that varied between moderate and large. Similarly, a moderate ($r = 0.3$; $p \leq 0.01$) to large ($r = 0.6$; $p \leq 0.01$) correlation was found between the relative (11.4 ± 3.7%) and absolute time (669 ± 223 s) spent in the MIVZ and the MI HR zone (41.0 ± 16.8% and 2253 ± 752 s). However, the true correlation value for the absolute time spent in the MI zone fell between the large to very large category, whereas the correlation for the relative time was small to moderate. There were no significant correlations ($p \leq 0.01$) between the HIVZ and the HI HR zone. Although some correlations were found from the Spearman's rank correlation, when adjusting for $\dot{V}O_{2max}$ and Yo-Yo IR1 performance these correlations became non-significant.

From these study results it is clear that the Yo-Yo IR1 and 40-m speed test show promise to be used as valid sports-specific field tests for determining ventilatory thresholds for each player, the heart rates that correspond to these thresholds and the different velocity thresholds. The authors therefore recommend that researchers use these methods in future to determine individualised HR and velocity zones in combination with the GPS analysis results to define both the internal and external match loads of soccer players. Results of these analyses could enable future coaches and sport scientists to develop match-specific conditioning programs that reflect both the internal and external demands of soccer matches

Keywords: match analyses, fatigue, oxygen consumption, velocity, soccer

OPSOMMING

INTERNE EN EKSTERNE WEDSTRYD DRUKLADINGS VAN UNIVERSITEITSVLAK SOKKER SPELERS: ‘n VERGELYKING TUSSEN METODES

Die behoefte bestaan daaraan om akkurate, betroubare en geldige data te bekom vir die assessering van die eksterne en interne drukladings van sokkerwedstryde, veral in die mate waarin dit verband hou met Suid-Afrikaanse sokkerspanne. Gevolglik was die doelwitte van hierdie studie eerstens om die uitputtingsgrade en -patrone van ’n kohort universiteitsvlak sokkerspelers tydens wedstryde te bepaal wanneer die GPS (global positioning system) gebruik word om die hoë-intensiteit-hardloopprestasies in opeenvolgende 5-minute-periodes te kwantifiseer. Tweedens, om die invloed van Yo-Yo IR1-bepaalde (Yo-Yo intermittent recovery test level 1) fiksheidstatus van ’n kohort universiteitsvlak sokkerspelers op uitputtingspatrone en -graad terwyl hulle wedstryde speel, te bepaal. Derdens, om die posisioneel-interne wedstrydladings van ’n kohort universiteitsvlak sokkerspelers vas te stel deur gebruik te maak van harttempo en die Yo-Yo IR1-bepaalde drempelwaardes. Laastens, om die wedstrydanalise-resultate van verskillende metodes te bepaal wat daarop gemik is om die eksterne en interne wedstrydlading van ’n kohort universiteitsvlak sokkerspelers te bepaal.

Daar is van geselekteerde groepe universiteitsvlak sokkerspelers (n = 10–13) verwag om ’n 40-m maksimum spoedtoets en die Yo-Yo IR1 tydens ’n periode van twee weke óf voor óf na elke geanaliseerde wedstryd te voltooi. Die harttempo- (HT) waardes en GPS-data van elke speler is tydens ligasokker-wedstryde opgeneem.

Vir die eerste en tweede doelwitte van die studie is spelers in drie aktiwiteitsvlak-kategorieë ingedeel (laag, matig en hoog) ooreenkomstig hulle aktiwiteitsvlakke in die eerste helfte van die wedstryd. Voorts is hul hoë-intensiteit-hardloop (> 3.7m/s) (HIH) in opeenvolgende 5-min-periodes gemonitor. Die lae-aktiwiteit-groep het ’n klein tot matige verskil ($p < 0.05$) in HIH 5 minute en 15 minute na die piekperiode getoon, vergeleke met die gemiddelde 5-minute-periode. Die matige-aktiwiteitsgroep het ’n matige verskil ($p < 0.05$) in HIH 5 minute na die piekperiode getoon. Die hoë-aktiwiteit-groep het matige tot groot afnames in afstand wat afgelê is tussen die eerste 15 minute van die tweede helfte (103.9 m/min) getoon vergeleke met die eerste 15 minute van die eerste helfte (122.5 m/min). Hulle het ook klein

tot matige afnames in HIH tydens die eerste 10 minute van die tweede helfte (25.7 m/min) getoon, vergeleke met die eerste helfte (34.1 m/min). Die lae-aktiwiteitsgroep het 'n geringe afname in afstand wat afgelê is tydens die eerste 5 minute van die tweede helfte getoon (76.3 m/min), vergeleke met die eerste helfte (87.7 m/min). Hierteenoor het die lae-aktiwiteits-groep 'n klein tot matige toename getoon in afstand wat afgelê is tydens die laaste 10 minute van die tweede helfte (95.7 m/min), vergeleke met die eerste helfte (84.4 m/min). Die Yo-Yo IR1 is nie betekenisvol met enige van die veranderlikes wat met HIH geassosieer word, gekorreleer nie.

Vir die derde doelwit van die studie is spelers se harttempo wat met die eerste en tweede ventileringsdrempel, soos tydens 'n Yo-Yo IR1 verkry, gebruik om harttempo in lae (LI HT-sone), matige (MI HT-sone) en hoë-intensiteit-sones (HI HT-sone) te klassifiseer. Resultate het getoon dat aanvallers meer tyd in die LI HT-sone deurgebring het (3 386 s; 62%; p <0.05) as verdedigers (2 155 s; 40%) en middelveldspelers (2 425 s; 42%). Die aanvallers het minder tyd in die HI HT-sone (260 s; 4%; p <0.05) as die verdedigers (964 s; 15%) deurgebring. Middelveldspelers (2 444 s; 44%) en verdedigers (2 364 s; 41%) het meer tyd in die MI HT-sone bestee as wat die aanvallers bestee het (1 854 s; 44%).

Vir die vierde doelwit van die studie is die spelers se snelheid en harttempo- (HT) drempels van die 40-m maksimumspoed-toets en die Yo-Yo IR1 bepaal. Resultate het 'n groot ($r = 0.5$; $p \leq 0.01$) korrelasie getoon tussen die tyd wat in die Lae Intensiteit Snelheid-sone (LISS) deurgebring is (5017 ± 368 s) en in die LI HT-sone (2891 ± 1086 s), met die ware korrelasiewaarde wat varieer tussen matig en groot. Eweneens is 'n matige ($r = 0.3$; $p \leq 0.01$) tot groot ($r = 0.6$; $p \leq 0.01$) korrelasie gevind tussen die relatiewe (11.4 ± 3.7%) en absolute tyd (669 ± 223 s) wat in die Matige Intensiteit Snelheid-sone (MISS) en die MI HT-sone (41.0 ± 16.8% en 2253 ± 752 s) deurgebring is. Die ware korrelasiewaarde vir die absolute tyd wat in die MI-sone deurgebring is, het egter tussen die groot en baie groot kategorie geval, terwyl die korrelasie vir die relatiewe tyd klein tot matig was. Geen betekenisvolle korrelasies ($p \leq 0.01$) het tussen die HISS en die HI HT-sone voorgekom nie. Hoewel sommige korrelasies uit die Spearman se rangkorrelasie gevind is, het hierdie korrelasies niebetekenisvol geword toe daar aangepas is vir $\dot{V}O_{2max}$ en Yo-Yo IR1-prestasie.

Uit hierdie studie-resultate is dit duidelik dat die Yo-Yo IR1 en 40-m spoedtoets belofte toon om gebruik te word as geldige sportspesifieke veldtoetse ter bepaling van snelheidsdrempels vir elke speler, en die harttempo wat met hierdie drempels korrespondeer en die verskillende snelheidsdrempels. Die outeurs beveel dus aan dat navorsers hierdie

metodes in die toekoms moet gebruik om geïndividualiseerde HT en snelheid-sones in kombinasie met die GPS-analise-resultate om beide die interne en eksterne wedstrydladings van sokkerspelers vas te stel. Resultate van hierdie analises kan toekomstige afrigters en sportwetenskaplikes help om wedstrydspesifieke kondisioneringsprogramme te ontwikkel wat beide die interne en eksterne eise wat sokkerwedstryde stel, weerspieël.

Sleutelwoorde: wedstrydanalise, uitputting, suurstofverbruik, snelheid, sokker

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LIST OF ABBREVIATIONS

ABBREVIATION	MEANING
℃	Degrees Celsius
ANOVA	Factorial analysis of variances
AR1	Autoregressive 1
Att	Attackers
bpm	Beats per minute
CI	Confidence interval
cm	Centimeter
Def	Defenders
EL	Extremely large
ES	Effect size
FIFA	Fédération Internationale de Football Association
GPS	Global Positioning System
HAG	High-activity group
HI	High-intensity
HIR	High-intensity running
HIVZ	High-intensity velocity zone
HIZ	High-intensity zone
HR	Heart rate
HR_{max}	Maximum heart rate
HR_{mean}	Mean heart rate
Hz	Hertz
ICC	Intra-class coefficient correlation

km	Kilometers
km/h; km h^{-1}	Kilometers per hour
kg	Kilogram
L	Large
LAG	Low-activity group
LI	Low-intensity
LIVZ	Low-intensity velocity zone
LIZ	Lowe-intensity zone
m	Meters
M	Moderate
MAG	Moderate-activity group
MI	Moderate-intensity
Mid	Midfielders
min	Minute
$m.min^{-1}$; m/min; m min^{-1}	Meter per minute
ml/kg/min; $ml.kg.^{-1}min^{-1}$	Milliliters per kilogram per minute
mM	Milimol
$m.s^{-1}$; m/s	Meter per second
$m.s^{-2}$; m/s^2	Meter per second squared
MIVZ	Moderate-intensity velocity zone
MIZ	Moderate-intensity zone
n	Sample size
p	Probability
r	Correlation coefficient
RCP	Respiratory compensation point
RER	Respiratory exchange ratio
RPE	Rating of perceived exertion
RSA	Repeated sprint ability
RSAT	Repeated sprint ability test
s	Seconds
SD	Standard deviation
SEE	Standard error of the estimate
TEM	Technical error of measurement

$\dot{V}CO_2$	Carbon dioxide production
$\dot{V}_E$	Minute ventilation
VL	Very large
$\dot{V}O_2$	Oxygen uptake
$\dot{V}O_{2max}$	Maximum oxygen uptake
VT	Ventilatory threshold
Yo-Yo IR1	Yo-Yo intermittent recovery test 1

CHAPTER 1

1 PROBLEM STATEMENT AND PURPOSES OF THE STUDY

1. INTRODUCTION

In order to increase athletic performance it is essential to develop valid and practical methods for quantifying exercise loads (Eniseler, 2005:799). Soccer is an intermittent sport where periods of activity differ in intensity and duration and are frequently interspersed with periods of rest or light activity (Drust *et al.,* 2007:37). Major developments in different match analysis technologies have enabled researchers to analyse the movement patterns of players during soccer matches (Carling *et al.,* 2008:840). The better the understanding of the specific loads placed on soccer players during match-play the more likely it will be that suitable training and recovery programs will be developed, which may lead to a decrease in injuries as well as an improvement in performance (MacLeod *et al.,* 2009:121).

2. PROBLEM STATEMENT

Soccer is the most popular sport in the world and is played both by men and women (Stolen *et al.,* 2005:502). In recent times, soccer as a professional occupation has become more attractive due to the financial rewards that have increased considerably (Reilly *et al.*, 2000:669). The popularity of soccer and the substantial financial rewards players and the coaching staff receive when achieving success have forced conditioning coaches and sport scientists to use more reliable and accurate methods to analyse the loads of matches, thereby enabling them to construct effective training programs (Carling, 2011:155; Reilly *et al.,* 2000:669). Several methods have been used to analyse and determine the loads of soccer matches, which include the following: manual video tracking (Bloomfield *et al.,* 2007; Burgess *et al.,* 2006; Mohr *et al.,* 2003), semi-automated video tracking (Bradley *et al.,* 2011; Carling, 2011; Dellal *et al.,* 2011; Carling, 2010), global positioning system (GPS) analyses (Buchheit *et al.,* 2011; Randers *et al.,* 2010) and heart rate monitoring and analysis (Mohr *et al.,* 2004; Helgerud *et al.,* 2001). Unfortunately, to date, no gold standard for determining the match loads of soccer has been established, but the results of studies that have made use of these above-mentioned methods have contributed to a better understanding of the demands of the game.

The emergence of GPS has allowed researchers and sport-related practitioners alike to make more accurate analyses of soccer matches in a time efficient manner (Barros *et al.*, 2007:233; Buchheit *et al.,* 2011; Randers *et al.,* 2010). GPS analysis is also less expensive than semi-automated video tracking (Di Salvo *et al.*, 2006:117). Studies that used GPS analyses suggest that semi-professional players cover an average distance of between 10 063 m and 10 274 m during soccer matches (Wehbe *et al.*, 2014:836; Mugglestone *et al.*, 2013:516; Varley *et al.,* 2013:4). Furthermore, Varley *et al.* (2013:4) and Wehbe *et al.* (2014:836) found that professional players covered these distances at an average intensity of 104 m/min and 109 m/min respectively. The volume of high-intensity activities performed during match-play has been found to be a valid measure of physical performance (Mohr *et al.*, 2003:526). Mugglestone *et al.* (2013:516) found that semi-professional players covered 16% of the total match distance (1 626 m) *via* high-speed running and 3% (305 m) *via* sprints. In contrast, Wehbe *et al.* (2014:836) indicated that professional players covered a distance of 2 258 m in the high-intensity running zone (running, high-speed running and sprinting). Research has found that the ability to perform high-intensity activities, as well as the total distance covered by semi- and professional soccer players declined during the second half compared to the first half (Mugglestone *et al.,* 2013; Di Salvo *et al.*, 2009; Mohr *et al.*, 2003). Several studies also found that there is a decline in high-intensity running during the final 15-min period of a soccer match (Bradley *et al.,* 2010; Bradley *et al.,* 2009; Mohr *et al.,* 2003). On the other hand, some investigations revealed that examining 15-min periods does not offer adequate sensitivity to monitor the fatigue experienced during match-play (Lovell *et al.,* 2013; Mohr *et al.,* 2003). Therefore several studies have used pre-determined 5-min intervals to monitor variations in high-intensity activities and found that after the most intense period during a match there was a drop below the match average in high-intensity activities during the subsequent 5-min period (Bradley & Noakes, 2013:1632; Bradley *et al.,* 2010:2348; Bradley *et al.,* 2009:162; Mohr *et al.,* 2003:525). Although monitoring high-intensity activities during 5- and 15-min periods indicate forms of temporary and permanent fatigue, using pre-determined intervals, could lead to under- or overestimations in the percentage of reduction in these activities (Bradley *et al.,* 2010:2349).

Some shortcomings in the literature exist that should be considered when using GPS to analyse soccer matches. In this regard, Portas *et al.* (2010:455) found that GPS with faster sampling rates (5Hz) were more accurate at higher speeds in small spaces than GPS with slower sampling rates (1Hz GPS). In a more recent study, Varley *et al.* (2012:125) concluded that the 10Hz GPS was two to three times more accurate in detecting changes in velocity and up to six times more reliable than the 5Hz GPS when data with regard to accelerations, decelerations and constant velocities were compared. Vickery *et al.* (2014:1702) also found that both the 10 and 15 Hz devices were valid in determining total distance covered and peak speed compared to the VICON motion analysis system (Oxford Metrics, Oxford, UK).

However, although indirect methods of measuring movement intensities provide valuable insight into the external match loads of players, it oversimplifies the analyses of complex movements, and does not allow researchers to directly measure the individual physiological responses of players to different movements (Duthie *et al.,* 2003:98). Studies in which the match heart rates of soccer players were monitored for determining internal loads have been reported, which concluded that the average heart rates during matches varied between 82 and 86% of the maximum heart rate (Mohr *et al.*, 2004:157; Helgerud *et al.,* 2001:1929). However, heart rate values alone do not allow researchers to make accurate assessments of individuals' soccer match intensities if oxygen uptake ($\dot{V}O_2$) and heart rates are not measured concurrently at a variety of intensities (Achten & Jeukendrup, 2003:525). The direct measurement of $\dot{V}O_2$ with a portable gas analyser during a graded maximal test allows researchers to identify two physiological gas exchange points, namely the ventilatory threshold (VT) and the respiratory compensation point (RCP) (Foster & Cotter, 2006:69). The heart rates that match the exercise intensities below the VT (low-intensity), between the VT and RCP (moderate-intensity) and above the RCP (high-intensity) can then be used to classify intensities during matches (Bompa & Haff, 2009:84; Foster & Cotter, 2006:73). However, to the author's knowledge no studies have used heart rate values and thresholds concurrently to determine individual players' soccer match intensities. Abt and Lovell (2009:896) used the ventilatory threshold values to analyse players' sprinting activities during soccer matches and concluded that players' individualised thresholds for high-intensity running were 24% lower than the traditional default values normally used by match analysis systems. The use of these individual incremental treadmill test-derived values resulted in a considerable increase (167%) in the total distances covered during high-intensity sprinting (Abt & Lovell, 2009:286). Sport scientists and coaches should therefore determine each soccer player's speed and intensity thresholds individually in order to establish the high-intensity heart rate ranges (Abt & Lovell, 2009:896–897).

Despite the fact that most researchers make use of a motorised treadmill to perform a graded maximal test for determining the $\dot{V}O_2$ values of athletes and players (Rampinini *et al.,* 2010; Abt & Lovell, 2009; Esposito *et al.,* 2004; Edwards *et al.,* 2003), the muscle recruitment patterns and energy demands during a soccer match will likely be different from those of the treadmill test. The movements during the treadmill-running test are continuous, forward running at constant speeds compared to a soccer match, which consists of running different distances, pivoting and making frequent changes in direction while regularly accelerating and decelerating. The emergence and use of the Yo-Yo intermittent recovery test level 1 (Yo-Yo IR1) (Bangsbo *et al.,* 2008:37) may provide sport practitioners and scientists alike with a more sport-specific test to measure the direct $\dot{V}O_2$ and the two physiological gas exchange points of soccer players. It is possible to determine these variables using the Yo-Yo IR1 with players wearing a portable gas analyser apparatus. Significant correlations ($p < 0.05$) also exist between Yo-Yo IR1 results and the amount of high-intensity running ($r = 0.71$), the distance covered ($r = 0.58$) during a soccer match and the amount of high-intensity running during the final 15-minute periods of each soccer match half ($r = 0.83$) (Krustrup *et al*., 2003:703; Krustrup *et al*., 2005:1245). These relationships enable researchers to not only use the Yo-Yo IR1 as an indicator of players' training status but also to determine the effect of training status on players' fatigue patterns and rate during match-play.

From the above-mentioned literature it is clear that a need exists to obtain accurate, reliable and valid data to assess the external and internal loads of soccer matches. An analysis of the available research also revealed that no researchers have thus far made an attempt to quantify the match loads of South African university soccer teams. The accurate quantification of university-level soccer match loads will possibly enable coaches and sport scientists of university-level soccer teams to compile specific and effective conditioning programs that prepare the players for the demands of match-play. It is in the light of this research background and identified shortcomings that the following research questions are posed: Firstly, what are the fatigue rates and patterns of a cohort of university-level soccer players during matches when using GPS to quantify the high-intensity running performances in rolling 5-min periods? Secondly, what influence does Yo-Yo IR1 performance of a cohort of university-level soccer players have on fatigue patterns and rate during match-play? Thirdly, what are the positional-internal match loads of a cohort of university-level soccer players when making use of heart rates and the Yo-Yo intermittent recovery test-determined threshold values? Lastly, how do the match analysis results of different methods aimed at determining the external and internal match loads of a cohort of university-level soccer players compare?

3. OBJECTIVES

The objectives of this study are to:

- Determine the fatigue rates and patterns of a cohort of university-level soccer players during matches when using GPS to quantify the high-intensity running performances in rolling 5-min periods.
- Determine the influence of Yo-Yo IR1-determined training status of a cohort of university-level soccer players on fatigue patterns and rate during match-play.
- Determine the positional-internal match loads of a cohort of university-level soccer players by making use of heart rates and the Yo-Yo IR1-determined threshold values.
- Compare the match analysis results of different methods aimed at determining the external and internal match loads of a cohort of university-level soccer players.

4. HYPOTHESES

This study is based on the following hypotheses:

- GPS-determined high-intensity running performances in rolling 5-min periods will indicate that activity levels during a match have a significant effect on the fatigue patterns and rates of a cohort of university-level soccer players.

- The Yo-Yo IR1-determined training status of a cohort of university-level soccer players will have a significant negative relationship with fatigue patterns and rates during match-play.
- The use of the heart rates and the Yo-Yo IR1-determined threshold values of a cohort of university-level soccer players will show significant positional differences in internal match loads.
- Due to a lack of research with regard to the comparison between methods to determine the internal and external match loads of university-level soccer players, it is difficult to compile a hypothesis for this part of the study. From the above-mentioned argument the researcher would, however, hypothesise that the results of this study will show that no significant relationships will exist between the external and internal match loads of a cohort of university-level soccer players.

5. STUCTURE OF THESIS

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

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

Chapter 2: Literature review: Methodologies to determine external and internal match loads of soccer players. A bibliography is provided at the end of the chapter in accordance with the guidelines of the North-West University.

Chapter 3: Article 1 – The use of a global positioning system to determine variations in high-intensity running and fatigue in a cohort of university-level soccer players. The article will be submitted for publication in the Journal of Science and Medicine in Sport. A bibliography is presented at the end of the chapter in accordance with the guidelines of the journal. Although not according to the guidelines of the journal, tables and figures will be included within the text so as to ease the reading and understanding of the text. Furthermore, the line spacing of the article will be set at 1.5 lines instead of the prescribed 2 lines.

Chapter 4: Article 2 – The use of heart rates and Yo-Yo intermittent recovery test-derived threshold values to determine the positional, internal match loads of university-level soccer players. The article will be submitted for publication in the Journal of Sport Sciences. A bibliography is presented at the end of the chapter in accordance with the guidelines of the journal. Although not according to the guidelines of the journal, tables and figures will be included within the text so as to ease the reading and understanding of the text. Furthermore, the line spacing of the article will be set at 1.5 lines instead of the prescribed 2 lines.

Chapter 5: Article 3 – Internal and external match loads of university-level soccer players: A comparison between methods. The article will be submitted for publication in the Journal of Strength and Conditioning Research. A bibliography is presented at the end of the chapter in accordance with the guidelines of the journal. Although not according to the guidelines of the journal, tables and figures will be included within the text so as to ease the reading and understanding of the text. Furthermore, the line spacing of the article will be set at 1.5 lines instead of the prescribed 2 lines.

Chapter 6: Summary, conclusions, limitations and recommendations.

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CHAPTER 2

2 LITERATURE REVIEW: METHODOLOGIES TO DETERMINE EXTERNAL AND INTERNAL MATCH LOADS OF SOCCER PLAYERS

1. Introduction

Soccer is one of the most popular sports in the world played by men, women and children (Tessitore *et al.* 2005:1365). The popularity of the sport as well as the substantial financial rewards offered for success (Reilly *et al.* 2000:669) have highlighted the importance of obtaining accurate and reliable data with regard to the movement and physiological match loads of soccer players. A greater understanding of the loads placed upon players during match-play may lead to the development of appropriate training regimens which may in turn lead to better performances and a decrease in injuries (MacLeod *et al.,* 2009:121). The match loads of soccer has been the subject of various research publications in recent years (Osgnach *et al.,* 2010:170) and major developments in different match analysis technologies have enabled researchers to simultaneously analyse the movement patterns of players and the general physiological loads of soccer matches (Carling *et al.,* 2008:840). Examining match loads can refer to the analysis of external loads (average distances covered, type of movements etc.) as well as internal loads (heart rate values, blood lactate concentrations, rating of perceived exertion [RPE] etc.) experienced by players during matches. In this regard semi-automated video tracking, manual video tracking and global positioning system (GPS) analyses are some of the most popular soccer match analysis methods that have been used over the past decade to determine the external loads experienced by players during match-play. However, several studies (Mohr *et al.,* 2004; Helgerud *et al.,* 2001) have also focussed on the internal loads experienced by players during match-play through the analyses of heart rate, RPE and blood lactate concentrations. Although both the external and internal loads experienced by players during matches are important, only a few studies have investigated methods that are aimed at analysing the internal loads players experience during soccer matches.

In view of the above-mentioned background, the objectives of this literature review was firstly to describe the various soccer match analysis methods cited in scientific literature as well as present the results of research that has used each of the methods to determine soccer match loads. Secondly, the author explored the limitations of the different methods and finally, paid attention to other methods that can also be applied to strengthen the accuracy and validity of soccer match analyses results. Searches of relevant English literature for this review were narrowed down to include articles from the last decade (2003–2014) which used male soccer players older than 18 years that had either played at club, provincial (national), or international level teams. Furthermore, only papers which included a detailed description of the study methods were considered. In order to achieve the last objective of this review, the authors also explored non-soccer-related literature that applied alternative analysis methods which may possibly have the potential of being used for soccer match analysis.

The soccer match analysis methods will be discussed under two categories, namely those that allow researchers to measure the external match loads of soccer players and those that allow researchers to measure the internal match loads of soccer players.

2. Methods to determine the external match loads of soccer players

Burgess *et al.* (2006:334) point out that the movement patterns of in-field sports are spontaneous, unpredictable and difficult to quantify. Periods of activity differ in intensity and duration and are frequently interspersed with periods of rest or light activity (Drust *et al.,* 2007:784). Furthermore, the characteristics of movements are unconventional with players regularly spinning, shuffling and moving diagonally during matches (Drust *et al.,* 2007:785). Nevertheless, many researchers have quantified these movements to provide sport scientists and coaches with a better understanding of the external match loads of soccer players. Table 1 contains a summary of various methods cited in literature that have been used to analyse the external match loads of soccer players.

Table 1: Various match analysis methods used by researchers to analyse the external match loads of soccer players

Authors	Nationality	Participation level	Method	Manufacturer
Abt & Lovell (2009)	English	Professional	Semi-automated video tracking	ProZone
Barros *et al.* (2007)	Brazilian	Professional	Semi-automated video tracking	DVideo
Bloomfield *et al.* (2007)	English	Professional	Manual video tracking	Player Cam (Sky Sports)
Bradley & Noakes (2013)	English	Professional	Semi-automated video tracking	ProZone
Bradley *et al.* (2009)	English	Professional	Semi-automated video tracking	ProZone
Bradley *et al.* (2011)	English	Professional	Semi-automated video tracking	ProZone
Burgess *et al.* (2006)	Australian	Professional	Manual video tracking	Trak Performance
Carling (2010)	French	Professional	Semi-automated video tracking	AMISCO Pro
Carling (2011)	French	Professional	Semi-automated video tracking	AMISCO Pro
Dellal *et al.* (2010)	French	Professional	Semi-automated video tracking	AMISCO Pro
Dellal *et al.* (2011)	English & Spanish	Professional	Semi-automated video tracking	AMISCO Pro
Di Mascio & Bradley (2013)	English	Professional	Semi-automated video tracking	ProZone
Di Salvo *et al.* (2007)	European	Professional	Semi-automated video tracking	AMISCO Pro
Di Salvo *et al*. (2009)	English	Professional	Semi-automated video tracking	AMISCO Pro
Di Salvo *et al.* (2010)	European	Professional	Semi-automated video tracking	ProZone
Dwyer & Gabbett (2012)	Australian	Professional	1 Hz GPS	MinimaxX, Catapult & SPI Elite, GPSports
Gregson *et al.* (2010)	English	Professional	Semi-automated video tracking	ProZone
Mohr *et al.* (2003)	European	Professional	Manual video tracking	Panasonic
Mugglestone *et al.* (2013)	Australian	Professional	1Hz GPS	SPI Elite, GPSports
O'Donoghue (2004)	English	Professional	Manual video tracking	Player Cam (Sky Sports)

Table 1 (cont.): Various match analysis methods used by researchers to analyse the external match loads of soccer players

Authors	Nationality	Participation level	Method	Manufacturer
Osgnach *et al.* (2010)	Italian	Professional	Semi-automated video tracking	SICS
Rampinini *et al.* (2007a)	European	Professional	Semi-automated video tracking	ProZone
Rampinini *et al.* (2007b)	European	Professional	Semi-automated video tracking	ProZone
Rampinini *et al.* (2009)	Italian	Professional	Semi-automated video tracking	SICS
Varley & Aughey (2013)	Australian	Professional	5 Hz GPS	SPI Pro, GPSports
Varley *et al.* (2013)	Australian	Professional	5 Hz GPS	SPI Pro, GPSports
Wehbe *et al.* (2014)	Australian	Professional	5 Hz GPS	SPI Pro, GPSports

From Table 1 it is obvious that semi-automated video tracking has been the preferred method to analyse the external match loads of soccer players during the past decade. From the 27 soccer match analysis studies identified, the majority of studies (18) used semi-automated tracking systems whereas studies using GPS and manual video tracking to analyse soccer matches accounted for five and four studies respectively. In view of the results that the majority of identified researchers made use of semi-automated video tracking as a match analysis method the next section will be dedicated to a discussion of this method and results obtained from using this method. This will be followed by the discussion of the manual video tracking and GPS match analyses methods.

2.1. Semi-automated video tracking

Semi-automated video tracking systems automatically locate and record the position of tracked objects (Barris & Button, 2008:1030). It analyses movement patterns in such a way that movement characteristics as well as work:rest ratios can be quantified (Di Salvo *et al.* 2006:109). Carling *et al.* (2008:843) provided a detailed description of how these systems work: several cameras are permanently fixed to the roof of a stadium to capture the entire surface of the field. The pitch and stadium are then calibrated in terms of height, length and width, which are transformed to a 2-D model in order to calculate the positional coordinates of players. Several methods (i.e. algorithms, trigonometry etc.) can then be used to identify specific players during match-play. Although the system is primarily automatic, it still requires some manual input from a trained operator. Different movement categories are then established based on movement velocities and are used to determine work:rest ratios. The categorisation for different movements during a match can also differ between studies and different systems. The most popular as well as a few alternative classifications will subsequently be discussed.

2.1.1 Movement categorisation for semi-automated video tracking systems

The locomotor movements performed during a match can be classified into different categories according to the velocity at which each movement is performed. The two main systems used for analyses (ProZone and AMISCO) employ different pre-defined classifications for movement analysis. In this regard the ProZone system uses the following classification to classify movements according to movement speeds (Bradley & Noakes, 2013:1628; Bradley *et al.,* 2009:160; Bradley *et al.,* 2011a:823; Di Mascio & Bradley, 2013:910; Rampinini *et al.,* 2007a:229; Rampinini *et al.,* 2007b:1019): standing (0–0.6 km/h), walking (0.7–7.1 km/h), jogging (7.2–14.3 km/h), running (14.4–19.7 km/h), high-speed running (19.8–25.1 km/h) and sprinting (> 25.1 km/h). High-intensity running is then used as a collective term for running, high-speed running and sprinting. Recovery time is defined as the time lapse between high-intensity running bouts (Bradley *et al.,* 2009:160; Bradley *et al.,* 2011a:823; Di Mascio & Bradley, 2013:910; Rampinini *et al*., 2007a:229; Rampinini *et al.,* 2007b:1019). The AMISCO system uses the following movement speed-related classification (Barros *et al.,* 2007:235; Carling, 2010:320; Carling *et al*., 2010:254; Dellal *et al*., 2010:280; Dellal *et al*., 2011:52; Di Salvo *et al*., 2007:223): 0–11 km/h (standing, walking, jogging), 11.1–14 km/h (low-speed running), 14.1–19 km/h (moderate-speed running), 19.1–23 km/h (high-speed running) and >23 km/h (sprinting). Although these classifications are used by two of the most cited systems (ProZone and AMISCO), several researchers have used modified or other classifications to describe movements.

For example, Di Salvo *et al.* (2009:206) and Gregson *et al*. (2010:238) used a modified version of the ProZone classification and described high-speed movements as follows: total high speed running (average running speed >19.8 km/h maintained for at least a 0.5 s time interval) and total sprint distance (average running speed >25.2 km/h maintained for at least a 0.5 s time interval). A different movement classification was used by Carling (2011:157) in a more recent study: 0.0–14.3 km/h (low-to-moderate intensity), 14.4–19.7 km/h (high intensity) and ≥ 19.8 km/h (very high intensity). Di Salvo *et al.* (2010:1490) mainly focussed on the total number of sprints, distance covered by sprinting as well as the percentage of each sprint type and classified sprints into the following: explosive sprints, which were described as sprints initiated by a fast acceleration from a standing position or from walking, jogging or running movements and occurred at a running speed of >25 km/h, without having entered the high-speed running zone in the previous 0.5 s. Leading sprints were described as sprints initiated by a gradual acceleration from a standing position or from walking, jogging or running movements and occurred at a running speed of >25 km/h without having entered the high-speed running zone in the previous 0.5 s. Sprints were also classified according to the different sprinting distances: 0–5.0 m, 5.1–10.0 m, 10.1–15.0 m, 15.1–20.0 m and >20 m (Di Salvo *et al.,* 2010:1490). Osgnach *et al.* (2010:172) used a different tracking system (SICS, Bassano del Grappa, Italy) with the following categories to describe movements: walking (0–8 km/h), jogging (8–13 km/h), low-speed running (13–16 km/h), intermediate-speed running (16–19 km/h), high-speed running (19–22 km/h) and maximal-speed running (> 22 km/h). They also described different acceleration and deceleration zones, namely maximal (< –3 m/s^2), high (–3 to –2 m/s^2), intermediate (–2 to –1 m/s^2) and low deceleration (–1 to 0 m/s^2) as well as low (0 to 1 m/s^2), intermediate (1 to 2 m/s^2), high (2 to 3 m/s^2) and maximum acceleration zones (3 to 4 m/s^2).

2.1.2 Validity, reliability and limitations of semi-automated video tracking systems for match analysis

Edgecomb and Norton (2006:31) found that their computer-based tracking system (Trakperformance, Sport-sTec Pty) overestimated the distances covered by players by 5.8 to 7.3%. In contrast, Bradley *et al.* (2009:161) and Di Salvo *et al.* (2006:117) reported that the ProZone system (ProZone version 3.0, ProZone Sports Ltd®, Leeds, UK) showed good inter- and intra-observer coefficient of variations for distances covered and could therefore be regarded as an accurate method for determining the distances players cover. The inter-observer coefficient of variation for total distances covered in all activity categories was <2% except for sprinting, for which a value of 3.5% was observed (Bradley *et al.,* 2009:161). Also, the intra-observer coefficient of variation for total distance covered in all movement categories was <2%, with the exception again of sprinting (2.4%) (Bradley *et al.,* 2009:161). Di Salvo *et al.* (2006:117) also concluded that the ProZone system was accurate in estimating running velocities on the pitch and that these velocities correlated highly (r = 0.99) with the values derived from timing gates.

Unfortunately certain limitations occur when applying semi-automated video tracking systems. Firstly, the installation of several cameras and the use of a semi-automated tracking system are extremely expensive and a dedicated operator is needed to run the data collection and analysis (Di Salvo *et al.,* 2006:117). Furthermore, analyses can only be done post-match (Carling *et al.,* 2005:41). Secondly, it is difficult to compare the match analyses results of different studies that have used semi-automated video tracking systems due to the fact that different velocity thresholds are used (Dellal *et al.,* 2010:279; Dwyer & Gabbett, 2012:818). Thirdly, this technique allows researchers to only measure the external match loads of players and does not provide researchers with direct information with regard to the internal load of different match play activities (Dellal *et al.,* 2012:2891). Fourthly, due to the cameras being attached to the roof of the stadium, teams are limited to the analysis of home games only. Finally, due to the fact that a huge amount of overlap exists between the speeds and accelerations of the above-mentioned movement classification categories, much confusion can be created for researchers that wish to use it to classify movements.

2.1.3 Results of semi-automated video tracking match analysis

Although researchers used different systems for analysing matches, they all reported more or less similar results with regard to the mean total distance covered (9–12 km) by players during matches (Barros *et al.,* 2007:237; Bradley *et al.,* 2009:162; Bradley *et al.,* 2011a:825; Carling, 2011:159; Di Salvo *et al.*, 2007:223; Rampinini *et al.,* 2007b:1021). While total distance covered during a match is important, the ability to repeatedly perform several sprints with minimal rest in between sprint intervals, also referred to as repeated sprint ability (RSA), is even more important to field-based team sports (Barbero-Alvarez *et al.,* 2010:232). Researchers are therefore much more inclined to focus their attention on high-intensity sprinting activities, which also include RSA, than on the mere distances covered during matches. For example, Di Salvo *et al.* (2009:207) found that wide-midfielders (1049 m) and defenders (911 m) as well as attackers (968 m) covered a significantly ($p < 0.05$) greater average distance at a high intensity than the central defenders (681 m), whereas attackers (262 m) and wide midfielders (260 m) covered a significantly ($p < 0.05$) greater average sprint distance than the central midfielders (217 m) as well as the central (167 m) and wide defenders (238 m). They also found that 31% of sprints executed during the match could be classified as explosive sprints and 69% as leading sprints. A similar study revealed that players performed an average of 136 sprints per match and covered an average distance in total of 205 m by sprinting (Di Salvo *et al.*, 2010:1491). Of these sprints, most were performed over an average distance of 0–5 m (Di Salvo *et al.*, 2010:1492). Twenty-three percent of these sprints were categorized as explosive sprints and 77% as leading sprints (Di Salvo *et al.,* 2010:1491).

Bradley *et al.* (2011a) compared positional differences across three playing formations. Although they did not test for significant differences between playing positions, they found that midfielders covered the greatest average distance by making use of very high (1 069 m) or high-intensity running (3 122 m) compared to attackers (992 m and 2 524 m) and defenders (787 m and 2 293 m) (Bradley *et al.,* 2011a:825). However, despite these differences midfielders had the least time (41 s) to recover between high-intensity movements compared to attackers (50 s) and defenders (64 s) (Bradley *et al.,* 2011a:825). An earlier study by Bradley *et al.* (2009:162) showed that players spent an average of 85.4% of the total match time in low-intensity movements, whereas 9.0% of the total match time was spent in high-intensity movements. The mean recovery time between high-intensity running activities was 72 s (Bradley *et al.,* 2009:162). Furthermore, Bradley *et al.* (2009:162) reported that players covered 17% and 21% more distance in high-intensity running during the first 15-min period of the first half compared to the last 15-min periods of the first and second halves respectively. The peak 5-min period of high-intensity running was 6% higher than the high-intensity distance covered in the subsequent period and the mean of all other periods. Osgnach and his colleagues (2010:173) found that players spent 87% of the total match time in walking or jogging activities, whereas only 3% of the total match time was spent in high- and maximum-speed running. They also observed that the players spent 78% of the total match time in the low deceleration and acceleration categories (Osgnach *et al.,* 2010:174).

In an attempt to establish whether players experienced fatigue during matches, several researchers also compared the match analyses results of first and second halves. In this regard Di Salvo *et al.* (2007:224) found that players covered a significantly ($p < 0.05$) greater average distance at a low-intensity in the second (3 535 m) compared to the first half (3 496 m). Also, players covered significantly ($p < 0.05$) greater distances at moderate intensities during the first (1 745 m) compared to the second half (1 668 m) (Di Salvo *et al.*, 2007:224). However, no significant differences were found between the first and second halves for the submaximal and maximal intensities (Di Salvo *et al.,* 2007:224). Bradley and his colleagues (2009:162) also indicated no significant differences in high-speed running and sprinting between the first and second halves, but showed that players performed more high-intensity bouts during the first half (n = 279) compared to the second half (n = 267). Bradley and Noakes (2013:1630) classified players into low, moderate and highly active groups according to the total distance covered in the first half and found that the total distance covered for players in the high and moderate groups declined significantly ($p < 0.01$) by between 4 and 7% during the second half, whereas it did not differ for the low activity group (Bradley & Noakes, 2013:1630). Furthermore the highly active group showed a 12% decline in the distance covered in high-intensity running during the second half. In addition to this Bradley and Noakes (2013:1629) determined the most intense period in the first half and analysed the subsequent 5-min periods. They found that there was an 8% decline in high-intensity running ($p < 0.01$) after the most intense period compared to the match average, but that players recovered back to mean values after the initial 5-min period.

2.2. Manual video tracking

Manual video tracking is another method that has been used by researchers and sport practitioners to track players' movements during match-play. Manual video tracking allows researchers to determine the requirements of field sports by quantifying the duration of, and distances covered during, various movements (Spencer *et al.,* 2006:1027). Manual video tracking is also regarded as an inexpensive technique for determining the technical demands of sport movements (Barris & Button, 2008:1027). Similar to semi-automated tracking systems, activities are also quantified into different movement categories (Duthie *et al.,* 2003:983). However, manual video tracking requires one or several observers to track players and their movements during video recordings, which is different from semi-automated tracking systems which automatically locate and record the position of tracked objects (Carling *et al.,* 2008:841). However, despite the use of this method since the 1970s (Spencer *et al.,* 2006:1026), only a few studies have applied this method over the last ten years for analysing soccer matches.

2.2.1 Movement categorisation for manual video tracking systems

Running, sprinting, shuffling as well as on the spot shuffling are usually classified under the work category, whereas standing, sitting, walking, jogging and lying in a prone position are all classified under the rest category (O'Donoghue, 2004:43). Mohr and colleagues (2003:520) divided movements into the following locomotor movements: standing (0 km/h), walking (6 km/h), jogging (8 km/h), low-speed running (12 km/h), moderate-speed running (15 km/h), high-speed running (18 km/h), sprinting (> 30 km/h) and backward running (10 km/h). In a further analysis these movements were divided into 4 broad categories, namely standing, walking, low-intensity running (jogging, low-speed running and backward running) and high-intensity running (moderate-speed running, high-speed running and sprinting) (Mohr *et al.,* 2003:520). The data of these movements were presented for 5-, 15-, 45-, and 90-min intervals (Mohr *et al.,* 2003:520). Although Burgess *et al.* (2006:336) used a similar classification for different movements, the velocities of these movements differed: walking (0–7 km/h), jogging (7–12 km/h), striding (12–18 km/h), sprinting (18–24 km/h) and maximum speeds (≥24 km/h).

2.2.2 Validity, reliability and limitations of manual video tracking for match analysis

Despite the benefits of manual video tracking, certain limitations need to be considered when this method is used for analysing soccer matches. For example, O'Donoghue (2004:47) found a significant systematic bias in both inter-observer ($p < 0.01$) and intra-observer agreement ($p < 0.05$) for the different high-intensity activities between matches evaluated. Di Salvo *et al.* (2006:109) also highlighted that manual video tracking mainly relies on the skills of the observer and the person analysing the video footage. This method is also extremely time consuming due to the fact that only one player can be analysed at a time (Barros *et al.,* 2007:233). Manual video tracking cannot be used to analyse activities during the match, but only afterwards (Edgecomb & Norton, 2006:26). Similar to the problem of the semi-automated tracking systems' movement classification categories, an overlap exists for the running velocities of the manual video tracking systems' activity classification categories which may make the categorization of movements difficult.

2.2.3 Results of manual video tracking match analysis

Similar to the results of semi-automated video tracking studies, Burgess *et al.* (2006:337) found that midfielders covered significantly ($p < 0.05$) greater distances (10.1 km) during matches than attackers (9.9 km) and defenders (8.8 km). Furthermore, Bloomfield *et al.* (2007:66) observed that defenders spent significantly ($p < 0.05$) less time running (7.6%) and sprinting (2.5%) than midfielders (14.6% and 6.4% respectively) and attackers (11.1% and 5.5% respectively). O'Donoghue (2004:46) mainly focussed his research on high-intensity movements and concluded that defenders (9.8%) and forwards (10.0%) spent a similar amount of the total match time in this intensity zone, with midfielders (11.0%) spending slightly more time in the high-intensity zone. The researchers did, however, not give any indication of the statistical significance of these differences.

Mohr and colleagues (2003:523) reported that players spent most of the total game time walking (43%), followed by low-intensity running (30.7%) and high-intensity running (9%). They also showed that players covered 14–45% less distance in high-intensity running during the last 15-min period than in the first four 15-min periods of the match (Mohr *et al.,* 2003:522). These researchers also observed a significant ($p < 0.05$) decrease in distance covered at high intensity during the 5-min period following the most intense 5-min period when compared to the average distance covered at high intensity during that half (Mohr *et al.*, 2003:525).

2.3. Global Positioning System (GPS) technology

The ability of portable data recording systems to process large amounts of data for motion tracking has improved over the last 10 years (Barris & Button, 2008:1026). Global positioning system (GPS) technology uses satellites around the earth to locate and track objects by receiving signals from these satellites via a transmitter (Barros *et al.,* 2007:233). GPS can give quantitative information on the position, displacement, velocity and acceleration of players during training or matches (Dwyer & Gabbett, 2012:818). However, similar to the above-mentioned methods, movements need to be classified into different categories according to velocities so that matches can be analysed.

2.3.1 Movement categorisation for GPS

Although Coutts and Duffield (2010:134) did not analyse a soccer match, they used the following categories and velocity bands for determining the accuracy and reliability of GPS devices: low-intensity movements (< 14.4 km/h), high-intensity movements (> 14.4 km/h) and very high-intensity movements (> 20 km/h). In a more recent study, Varley and Aughey (2013:35) used a more expanded categorisation: walking (0–2.1 m/s), jogging (2.2–4.16 m/s), high-velocity running (4.17–6.93 m/s), sprinting (≥ 6.94 m/s) and maximum acceleration (> 2.78 m/s^2). The velocities of sprinting and maximum acceleration overlapped and were therefore grouped together and termed high-intensity movements (Varley & Aughey, 2013:35). In the same year, Mugglestone *et al.* (2013:516) reported the following movement categories for soccer players in their study: walking (0–6 km/h), jogging (6–12 km/h), running (12–15 km/h), high-speed running (> 15 km/h) and sprinting (> 21 km/h). In the study of Varley *et al.* (2013:3) the following velocity thresholds or categories were used to describe movements: low-intensity activities (0–5.4 m/s), high-velocity running (≥ 5.5–10 m/s), sprinting (≥ 7–10 m/s) and maximal accelerations (≥ 2.78 m/s^2). They also categorised recovery periods between high-velocity running as short (< 30 s), moderate (30–120 s) or long (≥ 120 s) recovery periods. In a recent study by Wehbe *et al.* (2014:836), they describe the different activities as follows: standing (≤ 0.6 km/h), walking (0.6–7.1 km/h), jogging (7.2–14.3 km/h), running (14.4–19.7 km/h), high-speed running (19.8–25.1 km/h) and sprinting (> 25.2 km/h). Furthermore they described the accelerations and decelerations as follows: moderate-intensity (MI) accelerations (2.5–4.0 m/s^2), MI decelerations (-2.5–4.0 m/s^2), high-intensity (HI) accelerations (>4.0 m/s^2) and HI decelerations (<-4.0 ms^2). In an attempt to standardise movement categories, Dwyer and Gabbett (2012) investigated new velocity ranges and also provided a new definition for sprinting. They recommended the use of the following movement categories for male soccer players: standing (0.0–0.1 m/s), walking (0.2–2.0 m/s), jogging (2.1–3.7 m/s), running (3.8–6.0 m/s) and sprinting (6.1 m/s) (Dwyer & Gabbett, 2012:820). Movements were only classified into the sprinting category when players reached the sprint threshold velocity and/or when the movement acceleration occurred at the highest 5% of the velocity range (Dwyer & Gabbett, 2012:823).

2.3.2 Validity, reliability and limitations of GPS for match analysis

Unfortunately, as with the above-mentioned methods, GPS analysis has certain limitations that need to be considered when performing match analysis. A great number of studies have investigated the validity and reliability of the 1 and 5 Hz GPS. Portas *et al.* (2010:455) found that both the 1 and 5 Hz GPS (MinimaxX, Team 2.5, Catapult Innovations, Scoresby, Australia) devices were valid (Standard Error of the Estimate (SEE) = 2.6–2.7% and SEE = 2.9–3.1% respectively) to analyse multidirectional movements, but that the 1 Hz system did not provide valid and reliable values when multidirectional 180˚ turns were executed (Portas *et al.,* 2010:455). Jennings *et al.* (2010b) also compared the validity and reliability of 1 Hz and 5 Hz GPS devices (MinimaxX, Team 2.5, Catapult Innovations, Scoresby, Australia) to analyse movement patterns common to team sports. Their main findings indicated that both GPS devices underestimated repeated sprinting distances when sprinting took place over shorter distances (≤ 10 m) (Jennings *et al.,* 2010b:334). The higher sampling rate did, however, improve the validity of the measurements. The validity and reliability of distance measurements also improved (ie. <10%) as the criterion distances increased, but decreased as movement velocities increased (Jennings *et al.,* 2010b:339). In another study, Barbero-Alvarez *et al.* (2010:234) found a strong relationship between peak velocities over 15 and 30 m when measured with a 1 Hz GPS (SPI elite, GPSports, Canberra, ACT, Australia) device and timing gates. They also reported high test-retest reliability values for the repeated sprint ability test (RSAT) (Barbero-Alvarez *et al.,* 2010:234).

Gray *et al.* (2010) determined the validity and reliability of a 1 Hz GPS device (SPI elite, GPSports, Canberra, ACT, Australia) for measuring distances of movements that had taken place at different velocities and that were non-linear in nature. They found that the specific 1 Hz GPS device is valid and reliable when measuring slow, linear movements, but underestimated distances when participants performed high-velocity, non-linear movements (Gray *et al.,* 2010:1325). In a more recent study, Varley *et al.* (2012:122) examined the validity and reliability of a 5 Hz and 10 Hz GPS device (MinimaxX V2.0 and V4.0, Catapult Innovations, Scoresby, VIC, Australia) respectively during 80 straight-line sprints which consisted of accelerations as well as decelerations. The 10 Hz GPS device had a superior validity and inter-unit reliability compared to the 5 Hz GPS device (Varley *et al.,* 2012:126). The specific GPS device is therefore accurate enough to determine acceleration, deceleration and constant velocity movements in team sports. Similar to Varley *et al.* (2012), Rampinini and his collegues (2014) found the 10 Hz GPS to demonstrate low to moderate errors (1.9%–10.5%) for total distance, high-speed running (4.17 m/s) and very high-speed running (5.56 m/s). Therefore, in view of these research results it can be concluded that an increased sample rate will enhance the validity and reliability of GPS analyses (Jennings *et al.,* 2010b:339).

Jennings *et al.* (2010a) also examined the variability of two 5 Hz GPS devices (MinimaxX, Team 2.5, Catapult Innovations, Scoresby, Australia) placed on the same player while performing team sport-specific movements. They reported that the 5 Hz devices showed between-unit variability regardless of the distance covered, movement speeds and changes of direction that occurred (Jennings *et al.,* 2010a:568). Therefore, careful consideration should be given when comparing players especially if different GPS devices are used. In another study Coutts and Duffield (2010) determined the validity and reliability of 3 different 1 Hz GPS devices (SPI-10, SPI elite and WiSPI, GPSports, Canberra, Australia) and observed poor intra-model reliability between the different units when the results of very high-intensity running movements were compared (Coutts & Duffield, 2010:135).

Even further developments in GPS technology have led to the development of a 15 Hz GPS device (SPI-ProX, 15 Hz, Firmware V2.4.3, GPSports, Canberra, Australia). In essence this device is a 10 Hz GPS device to which an accelerometer was added in order to improve the sampling rate to 15 Hz (Aughey, 2011:306). Two recent studies used trained males to compare the 15 Hz system to the 10 Hz system (Johnston *et al.,* 2014; Vickery *et al.,* 2014). Johnston *et al.* (2014:1653) found that the 10 Hz GPS devices provided a valid measure (< 1% error) for total distance covered, but not for the determination of peak speed. Furthermore Johnston *et al.* (2014:1654) found that the inter-unit reliability of a 10 Hz device (1.6% error) was better than a 15 Hz unit (8.1% error) when peak speed was measured. They also found that the 10 Hz GPS device showed lower levels of error (< 14%) and stronger intra-class correlations (ICC) coefficients (> 0.8) than the 15 Hz device (%TEM =< 20%, ICC=>0.75) (Johnston *et al.,* 2014:1654). Further analyses also revealed that the 15 Hz GPS devices displayed contrasting results and were therefore not deemed to be valid measuring instruments for determining total distance and peak speed. Previous research by Waldron *et al.* (2011:1618) on youth male rugby league players also supported this finding by observing low validity when accelerometers were used to measure speed and distance. On the other hand, Vickery *et al.* (2014:1702) found that both the 10 and 15 Hz devices were valid in determining total distance covered and peak speed when compared to the VICON motion analysis system (Oxford Metrics, Oxford, UK).

Although GPS devices seem to be fairly accurate and reliable and provide a good alternative to the expensive semi-automated video tracking systems, accuracy and reliability are very much dependant on the sampling rate of the device. The higher the sampling rate, the more accurate the analyses of small movements at high velocities. Furthermore, in order for researchers and sport practitioners to determine soccer match loads, GPS devices need to be worn during matches and unfortunately Fédération Internationale de Football Association

(FIFA) does not allow players to wear GPS devices during official competitions (Barros *et al.,* 2007:233), which also include World Cups and Olympic Games (MacLeod *et al.,* 2009:127).

2.3.3 Results of GPS match analysis

Mugglestone and his colleagues (2013:516) found that players covered a total match distance of 10 163 m of which 16% was *via* high-speed running and 3% as sprints. However, they did not observe any significant differences in the number of high-speed runs or sprints between the first 15 minutes of each half (Mugglestone *et al.,* 2013:516). Varley and Aughey (2013:37) primarily focussed their study on running accelerations and found that soccer players performed 8 times more maximal accelerations during match-play than high-velocity efforts. They also showed that in the majority of cases players accelerated from a standing start, with 98% of maximum accelerations starting at a velocity of < 4 m/s (Varley & Aughey, 2013:37). Another study found that soccer players showed a significant ($p < 0.05$) decrease in the relative distance covered in total running (6%), low-intensity activities (6.1%) as well as the relative number of accelerations (3.6%) from the first to second halves (Varley *et al.,* 2013:5). Wehbe *et al.* (2014:836) indicated that professional players covered a distance of 2,258 m in the high-intensity running zone (running, high-speed running and sprinting).

Even though all the above mentioned techniques are of great value to better understand the external match loads of soccer players, all the methods use the same movement classification categories for all players. Individual differences in fitness levels and variations in exercise economy may therefore lead to errors in the estimation of movement classifications and intensities when using the same categories for all players. Generalizing the movement classification categories for all the players based on movement velocities may therefore not be the most accurate method to determine the movement intensities. The determination of each individual player's maximal speed and the use of a certain percentage of the maximal speed value to categorise the different players' movements, may provide one solution to this problem (Abt & Lovell, 2009:897). In this regard Abt and Lovell (2009:895) used a treadmill protocol to determine the second ventilatory threshold during a maximal oxygen uptake ($\dot{V}O_{2max}$) test. The running speed that corresponded to this threshold was used to categorise soccer match-play movements into high-intensity movements. They found that the point at which the high-intensity running occurred was 24% slower than the default guidelines proposed by the ProZone system (Abt & Lovell, 2009:896). Furthermore, the average distance covered at high-intensities using this individualised method was substantially higher (2 258 m) than when the default method (845 m) was used (Abt & Lovell, 2009:896).

Although indirect methods of measuring movement intensities provide valuable insight into the external match loads of players, it oversimplifies the analyses of complex movements, and does not allow researchers to directly measure the individual physiological responses of players to different movements (Duthie *et al.,* 2003:98). The use graded exercise tests to determine players' heart rates and maximal oxygen uptake may serve as more accurate methods for match analyses due to the fact that it will provide researchers an indication of the physiological strain (or internal match loads) of players. Therefore, the next section will focus on methods that allow researchers to determine the internal match loads of players.

3. Methods to determine the internal match loads of soccer players as well as other team-sport players

One of the major limitations of semi-automated video analysis systems and manual video tracking is that it only focuses on the external match loads of players. Researchers will only obtain reliable and accurate information with regard to the match loads of team sports if the last-mentioned methods are combined with methods that are used to measure the internal match loads of players (Dellal *et al.,* 2012:2891). One of the most common methods used to determine the internal load of sport participants during exercise is heart rate monitoring.

3.1. Heart rate monitoring

Heart rate monitoring is a valid method for determining and monitoring the physiological or internal loads experienced by players during match-play or training (Dellal *et al.*, 2012:2902). In spite of the validity of this method, only two studies that presented the match heart rates of adult male soccer players could be found. Tessitore *et al.* (2005:1370) reported that 49% of the total match time was spent above 85% of the maximum heart rate. It should however be noted that the average age of these players was 68.2 years. In another study, Edwards and Clark (2006:134) reported average heart rates of 159.2 bpm for the first and 153.2 bpm for the second halves of recreational matches. In spite of the availability of studies that analysed the match heart rate results of soccer players, researchers suggest that sport practitioners must use individualised heart rate zones when describing the heart rate responses of players during training and competitions (Dellal *et al.*, 2012:2895). However, only one study could be found which made use of individualised heart rate zones to categorise heart rates during soccer matches (Eniseler, 2005).

3.1.1 Results of an individualised heart rate zone study

Eniseler (2005:800) recommended the use of heart rates that corresponded to the 2 and 4 mM blood lactate concentrations that were obtained during a 20 m shuttle run, to analyse a pre-season professional soccer match. The results of their study showed that on average players spent 37% of the soccer match in the heart rate zone that corresponded to the heart rates between the 2 and 4 mM blood lactate concentration (Ensiler, 2005:801). Furthermore, 50% of the match time was spent in the heart rate zone which corresponded to the blood lactate concentration of above 4 mM (Ensiler, 2005:801). On average the soccer players maintained a mean heart rate of 157 bpm during match-play with a maximum heart rate of 203 bpm and a minimum heart rate of 60 bpm (Ensiler, 2005:801).

3.1.2 Limitations of heart rate monitoring

Although heart rate monitoring is an easy and inexpensive method to determine the internal match loads of players, heart rate can be influenced by several factors that are not only related to players' fitness levels. In this regard factors such as the condition of the playing field, the external temperature, humidity (weather), dehydration and emotional stresses are a few factors that may lead to estimation errors with regard to the internal match load of players (Dellal *et al.,* 2012:2901; Esposito *et al.,* 2004:167). Therefore, these factors need to be monitored closely when using heart rate to describe the internal match loads of players.

3.2. Rating of perceived exertion (RPE)

RPE represents the player's perception of exhaustion and is determined by both the physiological and the psychological stress that the player experience (Impellizzeri *et al.,* 2004:1045). RPE can therefore be considered to be a good indicator of the internal training load (Impellizzeri *et al.,* 2004:1046). Although no one has thus far investigated the validity of using RPE during soccer matches, Impellizzeri *et al.* (2004:1046) observed a moderate correlation between RPE and HR-based methods to determine internal training load. However, they also concluded that RPE is not a valid substitute for HR monitoring and should rather be used in conjunction with HR-based methods (Impellizzeri *et al*., 2004:1046). Nevertheless, the logistics of monitoring RPE continuously during soccer matches make it an impractical method to continuously determine internal match loads of soccer players.

3.3. The combined use of heart rates and graded maximal test values

Cardiorespiratory exercise testing during which graded maximal tests are performed may enable researchers to categorise heart rates into different intensity zones according to reference heart rate values (Esteve-Lanao *et al.,* 2005:496). The different intensity zones can then be applied to determine match-play and training intensities (Esteve-Lanao *et al.,* 2005:496). Esposito *et al.* (2004:172) also concluded that the results of laboratory reference tests together with the match heart rate values of players may enable researchers to determine the physiological on-field loads that players experience. In view of these statements, the next section will be dedicated to different studies that used either maximal laboratory or field tests to categorise the heart rates of individual players.

3.3.1 Results of studies that used heart rates and graded maximal test values

Castagna *et al.* (2007:91) considered futsal players' maximum heart rates (HR_{max}) to be the maximum heart rate achieved during a maximum oxygen uptake ($\dot{V}O_{2max}$) test in either the laboratory or on the field. Heart rates of futsal matches were then classified into the following categories: low (< 70% of individual HR_{max}), moderate (70–80% of individual HR_{max}) and high intensity (> 85% of individual HR_{max}) zones. They found that heart rates achieved by players during intermittent field movements may have a lower ability to predict aerobic involvement when compared to continuous exercise (Castagna *et al.,* 2007:93). Barbero-Alvarez *et al.* (2008:65) monitored the heart rates of players during 4 futsal matches. They used the HR_{max} that each player obtained during the match to determine intensity zones, although these heart rates were found to be 1–3 bpm higher than the maximal treadmill-determined heart rates. The heart rates during match-play were classified according to the following categories: supra-threshold or very vigorous (> 85% HR_{max}), aerobic or moderate zone (65–85% HR_{max}) and sub-aerobic or low intensity zone (< 65% HR_{max}) (Barbero-Alvarez *et al.,* 2008:66). The mean heart rate for the 4 matches that were analysed was 174 bpm. They also discovered that 83% of the match was spent in the very vigorous category, with the players spending 16% and 0.3% of the total game time in the moderate and low category respectively (Barbero-Alvarez *et al.,* 2008:68).

Castellano and Casamichana (2010) determined heart rate intensities of beach soccer matches by using heart rates and GPS values. The Yo-Yo Intermittent Recovery Test 1 (Yo-Yo IR1) was performed by each player to determine the HR_{max}. Each player's heart rates were then categorized according to his HR_{max}: < 75% HR_{max}, 76–84% HR_{max}, 85–89% HR_{max} and > 90% HR_{max} (Castellano & Casamichana, 2010:99). They reported that the mean heart rate during the match corresponded to 86.5% of the HR_{max} (Castellano & Casamichana, 2010:100). Furthermore, they found that players spent 59.3% of the total match time in the > 90% HR_{max} zone (Castellano & Casamichana, 2010:99). Sparks and Coetzee (2013:509) used a standard graded maximal treadmill test to determine two thresholds, namely the ventilatory threshold (VT) and the respiratory compensation point (RCP) of Rugby Union players. The VT was determined by using the criteria of an increase in $\dot{V}_E/\dot{V}O_2$ with no increase in $\dot{V}_E/\dot{V}CO_2$ and departure from the linearity of $\dot{V}_E$ (Chicharro *et al.,* 2000:452). The RCP was the point that corresponded to an increase in both $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$ (Chicharro *et al.,* 2000:452). The heart rates that corresponded to these thresholds were then used to classify the heart rates into low-, moderate- and high-intensity zones for use during match analyses. The match analyses revealed that players spent 44% of the match time in the high-intensity zone (170–185 bpm) and only 23% of the time in the low-intensity zone (141–152 bpm) (Sparks & Coetzee, 2013:510).

3.3.2 Limitations of the combined use of heart rates and graded maximal test values

Larsson (2003:1094) stated that most physiological tests are conducted in a controlled laboratory environment and cannot be used to describe and analyse sport-specific situations. In this regard, Sparks and Coetzee (2013:512) also concluded that more sport-specific field tests should be used to determine the different threshold dependent heart rates instead of physiological tests in a laboratory. Team sports such as soccer consist of running different distances, pivoting and making frequent changes in direction while constantly accelerating and decelerating (Sparks & Coetzee, 2013:512). The movements during the treadmill running test are continuous, forward running at constant speeds (Sparks & Coetzee, 2013:512). The muscle recruitment patterns and energy demands during a team sport match will therefore be different from those of the treadmill test (Sparks & Coetzee, 2013:512).

The development of portable wireless heart rate monitors and gas analyser apparatus have made it possible to use a more soccer specific incremental test to determine the two ventilatory threshold points for categorisation of the different heart rate intensity zones. In view of this development the potential of using a more soccer-specific field test to determine the different heart rate intensity zones for use in soccer match analyses will be explored in the next section.

4. The use of the Yo-Yo IR1 to determine the different heart rate intensity zones for soccer match analyses

Traditional laboratory tests used for the evaluation of athletes' aerobic and anaerobic fitness do not simulate the movement patterns of soccer due to their continuous nature (Meckel *et al.,* 2009:164). Similarly, Bradley *et al.* (2011b:970) pointed out that most tests for determining $\dot{V}O_{2max}$ are continuous in nature whereas soccer is intermittent in nature and consists of several bouts of high-intensity activities interspersed by low-intensity activities. Additionally, Svensson and Drust (2005:608) stated that laboratory testing should be used as a tool to evaluate general fitness and not sport-specific fitness. A test that meets all the requirements to possibly serve as a more soccer-specific test to determine the $\dot{V}O_{2max}$ and different HR intensity zones of players, is the Yo-Yo IR1. The Yo-Yo IR1 is a validated exercise test that ensures that subjects reach their $\dot{V}O_{2max}$, with a significant correlation established between $\dot{V}O_{2max}$ and Yo-Yo IR1 results (r = 0.70; p <0.05) (Bangsbo *et al.*, 2008:47). The Yo-Yo IR1 has been widely applied in many team sports to evaluate players' abilities to repeatedly perform high-intensity exercise (Bangsbo *et al.,* 2008:38). The Yo-Yo IR1 can also be used to determine the HR_{max} of players (Bangsbo *et al.,* 2008:39).

Krustrup *et al.* (2003:703) found that Yo-Yo IR1 results significantly (p <0.05) correlated with the amount of high-intensity running (r = 0.71) as well as the distance covered (r = 0.58) during a soccer match. They further reported a significant correlation (p <0.05) between Yo-Yo IR1 results and the amount of high-intensity running during the final 15-minute periods of each soccer match half (r = 0.83) (Krustrup *et al.*, 2005:1245). Although the last-mentioned study used elite female soccer players as study subjects, Mohr and colleagues (2010:129) also found a significant relationship between distance covered during the Yo-Yo IR1 and the amount of high-intensity running during the final 15 minutes of an elite male soccer match (r = 0.51). Therefore, these studies suggest that a significant correlation exists between training status and fatigue development during soccer matches (Krustrup *et al.,* 2005; Mohr *et al.,* 2010).

From the above-mentioned findings it is apparent that the Yo-Yo IR1 can possibly be used as a more sport specific field test to possibly predict the fatigue that soccer players will experience during match play as well as the different HR intensity zones that can be applied to analyse soccer matches. HR intensity zones can be determined by attaining the VT and the RCP of players if each player runs the Yo-Yo IR1 while fitted with a valid portable gas analyser apparatus (Macfarlane & Wong, 2012; Vogler *et al.,* 2010) and a Fix Polar Heart Rate Transmitter Belt. Although no studies could be found that have tested this notion, Girard *et al.* (2005) proved that a squash specific field based test could be used to determine the VT and RCP of squash players. They also identified different heart rate intensity zones by making use of this method (Girard *et al.,* 2005:925). Interestingly they found that there were no differences in VT and RCP heart rates and percentage of $\dot{V}O_{2max}$ values when the results of the treadmill test were compared to the results of the sport-specific field test (Girard *et al.,* 2005:924).

5. Conclusion

Although many studies have described either the external or internal match loads of soccer players, very few have used a combination of methods to determine both types of loads during match-play. In view of this problem the objectives of this literature review was firstly to describe the various soccer match analysis methods that are cited in scientific literature as well as present the results of research that has used each of the methods to determine soccer match loads. Secondly, the author explored the limitations of the different methods and finally, provided a review of other methods that can also be applied to strengthen the accuracy and validity of soccer match analyses results.

The soccer match analysis methods were discussed under two categories, namely those that allow researchers to measure the external match loads of soccer players and those that allow researchers to measure the internal match loads of soccer players. The results of semi-automated video tracking soccer match analyses studies revealed that the average total distance covered per match by players was 9–12 km. Literature also showed that midfielders covered significantly ($p < 0.05$) greater distances in the high-intensity zone (4 191 m) compared to attackers (3 446 m) and defenders (3 080m). No difference in the amount of time spent in high-intensity activities between halves were reported. However, there was evidence of a significant decrease in high-intensity activities after a period of peak high-intensity activities. Although semi-automated video tracking systems were found to be fairly accurate, the following limitations need to be considered by users of this systems: users are confined to the area of installation; the systems are extremely expensive; a well-trained operator is needed to run the data collection and analysis; lastly the systems make use of a variety of velocity thresholds between studies, which hamper comparisons.

The affordability of manual video tracking systems has compelled various researchers to make use of this method to analyse the external match loads of soccer players. Movement classifications used during manual video tracking are comparable between studies however the velocity bands at which the different classifications start differ considerably. Similar to the results of semi-automated video tracking systems, manual video tracking related studies confirmed that midfielders do the most work during match-play. Studies also found that players spent 9–11% of the total match time on average in the high-intensity zone. Furthermore it was reported that players spent a considerable amount of time in the walking

(43%) and low-intensity running zone (31%). Researchers also showed that there was a significant decrease ($p < 0.05$) in distance covered (14–45%) in high-intensity running during the last 15-min period compared to the first four 15-min periods of the game. Unfortunately manual video tracking analyses are very time-consuming and its accuracy is dependent on the skill and experience of the observer.

In contrast with manual video tracking analyses, the availability of GPS has made it possible for researchers to analyse matches in real-time. In addition to the normal movement classifications found in semi-automated and manual video tracking studies, acceleration and deceleration categories were added to GPS analysis studies. GPS-related studies found that players covered an average distance of approximately 10 km during a match. Studies also determined that the average time spent in high-intensity movements was 19%. Regrettably FIFA laws do not allow players to wear GPS units while they are playing soccer matches which make GPS monitoring of FIFA accredited soccer matches impossible. The accuracy of GPS is also very dependent on the sampling rate of the units with units that sample at a higher rate showing greater accuracy. However, GPS units that depend on an accelerometer to increase the sampling rate as is the case with some 15 Hz GPS units, tend to be less accurate.

Although all the above-mentioned systems are valuable for determining the external match loads of soccer players, the results of match analyses alone are not a true reflection of the demands of soccer match-play if the internal match loads of players are not determined. The monitoring of heart rates, RPE and the combined use of heart rates and graded maximal test values enable researchers to also determine players' internal match loads. Only one study could be found that used individualised, blood lactate-determined heart rate zones for each player and reported that players spent 50% of the time in the highest intensity zone (> 4mM blood lactate concentration). The use of RPE to quantify the internal load of training sessions can also be valuable, but should not substitute HR monitoring. The use of this measure in soccer match situations has also not been investigated. A further examination of literature revealed that several studies used heart rates as well as graded maximal test results to determine the match loads of team-related sports. Although this method was used on different team sports, the majority of studies found that the players spent the highest percentage of match time (44%–83%) in the high-intensity zone. Unfortunately researchers made use of laboratory instead of field-based tests for determining the different HR intensity zones. Differences in the muscle recruitment patterns and energy demands between an intermittent sport match and a laboratory test make the use of sport-specific maximal tests to determine different heart rate intensity zones of players more accurate and relevant.

A test that meets all the requirements to possibly serve as a more soccer-specific test for determining the $\dot{V}O_{2max}$, different HR intensity zones as well as training status of players for possible prediction of fatigue development during soccer matches is the Yo-Yo IR. However, up until now no researchers have determined the $\dot{V}O_{2max}$ and different HR intensity zones of players by making use of the Yo-Yo IR1. Despite this, one study did examine the use of a squash-specific field-based test for determining squash players' heart rate intensity zones. However, they found no differences in VT and RCP heart rates and percentage of $\dot{V}O_{2max}$ values when the results of the treadmill test were compared with the results of the sport-specific field test.

In conclusion, from this literature review it is clear that there is a need to use methods to simultaneously analyse both the internal and external match loads of players. It is also evident that GPS analysis is more accurate than manual video tracking and less expensive than semi-automated video tracking. The literature presently contains a rather large amount of data concerning the external match loads of soccer players, but insufficient data exists with regard to the internal match loads of soccer players. Also, until recently, only a few researchers have made an attempt to develop methods that can be used to accurately determine the internal load of team sport participants during match-play. The Yo-Yo IR1 test does show promise to be used as a valid sports-specific field test for determining individualised ventilatory thresholds as well as the heart rates that correspond to these thresholds in order to determine the match intensities of soccer players. The author of this review therefore recommends that researchers in future use the Yo-Yo IR1 test-obtained individualised HR zones in combination with the GPS analysis results for determining both the internal and external match loads of soccer players. Results of these analyses could enable future coaches and sport scientists to develop match-specific conditioning programs that reflect both the internal and external demands of soccer matches.

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CHAPTER 3

3 THE USE OF A GLOBAL POSITIONING SYSTEM TO DETERMINE VARIATIONS IN HIGH-INTENSITY RUNNING AND FATIGUE IN A COHORT OF UNIVERSITY-LEVEL SOCCER PLAYERS

TITLE: The use of a global positioning system to determine variations in high-intensity running and fatigue in a cohort of university-level soccer players

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Abstract

Objectives: To determine the fatigue rates and patterns of soccer players during matches when using global positioning system (GPS) to quantify the high-intensity running (HIR) performances in rolling 5-min periods.

Design: The Yo-Yo intermittent recovery test level 1 (Yo-Yo IR1) was performed before 12 soccer matches and GPS data were collected from 28 male players (age 22.1 ± 2.5 years) during each match.

Methods: Match data was categorised into total distance covered and high-intensity running (HIR) (>3.7 m min^{-1}). These variables were determined for rolling 5-min intervals. Distance covered in the first half were used to classify players into low- (LAG), moderate- (MAG) and high-activity groups (HAG).

Results: The LAG showed a small to moderate difference in HIR at 5 min and 15 min after the peak period compared to the average 5-min period. The MAG showed a moderate difference in HIR at 5-min after the peak period. The HAG showed moderate to large declines in distance covered between the first 15 min of the second half (103.9 m min^{-1}) and the first half (122.5 m min^{-1}). They also showed small to moderate declines in HIR during the first 10 min of the second half (25.7 m min^{-1}) compared to the first half (34.1 m min^{-1}). The LAG showed a small decline in distance covered during the first 5 min of the second half (76.3 m min^{-1}) compared to the first half (87.7 m min^{-1}). Conversely the LAG showed a small to moderate increase in distance covered during the last 10 min of the second half (95.7 ± 17.9 m min^{-1}) compared to the first half (84.4 ± 17.4 m min^{-1}).

Conclusions: First half activity profiles had a significant impact on recovery after the most intense 5-min period as well as second half performance. This suggests a degree of transient fatigue.

1. Introduction

Soccer is an intermittent sport in which periods of activity differ in intensity and duration and are frequently interspersed with periods of rest or lower-intensity activity.[1] Major developments in different match analysis technologies have enabled researchers to analyse the movement patterns of players during soccer matches.[2] Global positioning system (GPS) analysis can provide researchers with quantitative information on the displacements and velocities of players during training or matches due to its ability to process large amounts of data for motion tracking.[3-4] One of the benefits of GPS analysis is that researchers can track the duration of high-intensity activities players perform during certain time periods of the match and can use changes in the number of these activities to determine the rate of fatigue.[5-7] However, research suggests that the training status of players may influence the pattern and rate of fatigue during match-play.[8] Despite this, very few researchers have analysed changes in high-intensity activities over the duration of a soccer match in order to determine fatigue rate. Furthermore, no researchers have to date investigated the possible influence of training status on the fatigue pattern and rate of soccer players during match-play.

One of the valid measures for physical performance is the volume of high-intensity activities performed during match-play.[9] In this regard, Mugglestone et al.[5] found that semi-professional players covered 16% of the total match distance (1626 m) *via* high-speed running and 3% (305 m) *via* sprints. On the other hand, Varley et al.[10] concluded that professional soccer players only covered a distance of 517 m and 93 m through high-speed running and sprinting respectively. In contrast, Wehbe et al.[11] indicated that professional players covered a distance of 2 258 m in the high-intensity running zone. However, the ability to perform high-intensity activities, as well as the total distance covered by semi- and professional soccer players declines during the second half compared to the first half.[5,9,12] Furthermore, several studies found a decline in high-intensity running towards the final 15-min period of a soccer match.[8,13,14] However, other investigations revealed that examining 15-min periods throughout a match was inadequate to monitor fatigue experienced during matches.[9,15] Therefore several studies used pre-determined 5-min intervals to monitor variations in high-intensity activities and found that after the most intense period a decline below the match average in high-intensity activities during the subsequent 5-min period occurred.[8,13,14,16] Although monitoring high-intensity activities during 5- and 15-min periods indicate periods of transient fatigue, using pre-determined intervals, could lead to under- or overestimations in the percentage of reduction in these activities.[14] Therefore Varley et al.[6] suggest using a rolling time scale which determines the distance covered after every time point for the next 5-min period

The Yo-Yo intermittent recovery test level 1 (Yo-Yo IR1) has been applied in many team sports to evaluate players' ability to repeatedly perform high-intensity exercise.[17] Krustrup et al.[18] found that Yo-Yo IR1 results significantly ($p < 0.05$) correlated with the amount of high-intensity running (HIR) (r = 0.71) as well as the distance covered (r = 0.58) during soccer matches. They further reported a significant correlation ($p < 0.05$) between Yo-Yo IR1 results and the amount of HIR during the final 15-minute periods of each soccer match half in elite female soccer players (r = 0.83).[19] Mohr and colleagues[8] also found a significant relationship between distance covered during the Yo-Yo IR1 and the amount of HIR during the final 15 minutes of an elite male soccer match (r = 0.51). These relationships may therefore enable researchers to not only use the Yo-Yo IR1 as an indicator of players' training status but also to determine the effect of training status on players' fatigue patterns during match play.

However, it is still unknown whether a relationship exists between training status, as determined by the Yo-Yo IR1, and the reduction in HIR after the most intense 5-min period as an indicator of fatigue rate. In view of the above-mentioned gaps in the literature, the aims of this study were to: (1) determine the fatigue rates and patterns of a cohort of university-level soccer players during matches when using GPS to quantify the high-intensity running performances in rolling 5-min periods and (2) to determine whether the training status of a cohort of university-level soccer players has an influence on the way players regulate their high-intensity activities during match-play.

2. Methods

We used participants from the first soccer team of a university in the North West Province of South Africa. Information was obtained by means of a questionnaire and a test battery. The objectives as well as possible risks of the study were explained to the players, after which they completed an informed consent form. The study was approved by the Health Research Ethics Committee of the Faculty of Health Sciences of the institution where the research was conducted (NWU-00200-14-A1). The study was conducted according to the ethical guidelines and principles of the international Declaration of Helsinki. Twenty-eight male players (age 22.1 ± 2.5 years; stature 172.5 ± 7.5 cm; mass 63.5 ± 9.6 kg) were analysed during 12 A-league soccer matches. Goalkeepers were not included in the study. For the players' data to be included in the study they had to spend at least 50% of the game on the field. In other words in cases where players for some or other reason left the field before 50% of game time elapsed, the match data for that participant was excluded. The participants also needed to complete a Yo-Yo IR1 at least two weeks before or after each match and the participants also needed to be injury free at the time of testing. All players not adhering to these criteria were excluded from the study.

A significant correlation between maximal aerobic oxygen uptake ($\dot{V}O_{2max}$) and Yo-Yo IR1 results (r = 0.70, $p < 0.05$) provides evidence that the Yo-Yo IR1 is a valid exercise test for determining $\dot{V}O_{2max}$.[17] All players were familiar with the Yo-Yo IR1 as they had performed it previously. The test was conducted on a flat, clearly marked 20 m stretch of a grass soccer field. Players wore their soccer boots during the test. Players were required to run back and forth on the 20-m track and pace themselves so that the arrival at the end of the 20-m stretch coincided with the signal that was emitted from a commercially available pre-recorded compact disc (CD) (Bangsbosport.com, Bangsbosport Aps, Espergaerde, Denmark). Players were required to cross the marked lines at either end of the 20-m stretch with one foot as the signal sounded from the CD. Players received a brief 10-s active recovery after each 40-m (2 x 20 m) shuttle during which they walked back and forth over a 5-m stretch. The test started at a speed of 10 km h^{-1} and progressively increased until test termination. The test was terminated due to players voluntarily stopping or when a player could not make it to either end marks of the 20-m distance within the given signal time in two successive shuttles.

The GPS data of the starting line-up were monitored for the duration of several matches. Matches were analysed with GPS units sampling at a frequency of 10 Hz (MinimaxX V4.0, Catapult Innovations, Victoria, Australia) with a minimum of 8 satellites used to determine the position of each unit. The units were kept under open sky and turned on 10 min before they were fitted to the upper back of each player by means of a harness. Players were familiar with the GPS equipment and regularly trained with the units fitted to their backs. Data were obtained with regard to the distances and velocities of all movements that were executed during each soccer match. The recordings from the GPS unit were downloaded to a PC and analysed by making use of the Logan Plus V4.7.1 software (Catapult Sports, Victoria, Australia). The GPS Doppler data was used during the analyses of the GPS-related variables.

Several studies tested the validity and reliability of the 10 Hz GPS units[20-21] and Johnston et al.[21] concluded that the inter-unit reliability of the 10 Hz devices was good (TEM 1.64%) when peak speed was measured. The units were also found to be reliable for measuring instantaneous velocity (coefficient of variation 1.9–6.0%).[20]

For a movement to be recorded as an effort, players had to maintain that velocity for at least 1 s. The absolute (m) and relative (m min^{-1}) total distance covered by players as well as the absolute (m) and relative (m min^{-1}) distance covered at a velocity >3.7m s^{-1} were recorded for each player during the matches. This threshold for HIR coincides with previous studies.[22-24] During the matches the most intense period was classified as the peak distance covered in HIR for a 5-min interval from every time point (e.g. 0–5 min, 1–6 min etc.) sampled. To monitor the recovery after this period comparisons were drawn between the average 5-min period (excluding peak) and the subsequent 5-min periods up to a maximum of 15 min.[6,16] In a further analysis the distance players covered during the first half was classified as low, moderate and high to compare performance during pre-defined 5-min periods in the second half. The data were sorted using percentiles to produce each level (low: ≤30th percentile; moderate: 35–65th percentile and high: ≥70th percentile) according to the method described by Bradley and Noakes.[16]

Analyses were conducted using IBM SPSS Statistics v. 21.0.0.0. Descriptive statistics were calculated and all variables were normally distributed. Firstly, a bivariate correlation was performed to determine whether fitness (as measured by the Yo-Yo IR1) correlated with any of the match variables. Secondly, a factorial analysis of variance (ANOVA) test was performed to determine whether differences existed between the low-, moderate- and high-activity groups (based on first-half performance) for all variables. A Bonferroni post-hoc test was subsequently performed to determine significant differences between these groups. Thirdly, a dependant *t*-test was performed to determine whether any differences occurred between the most intense periods of the match and the subsequent periods. A dependant *t*-test was also done to determine any differences between the pre-determined periods of the match. The p-value was set at ≤ 0.05. Furthermore, effect sizes (ES) and 90% confidence intervals (CI) were calculated to determine the practical significance of differences between activity groups and periods. Effect sizes (ES) were interpreted using a scale of magnitudes: trivial (<0.2), small (0.21–0.6), moderate (0.61–1.2), large (1.21-2.0) and very large (>2.0).[25]

3. Results

The Yo-Yo IR1 was not correlated with any of the variables associated with HIR and recovery. Table 1 shows the Yo-Yo IR1 and match variables for all the activity groups. The peak 5-min period (62.5 ± 25.7 m min^{-1}) of the high-activity group was significantly (p ≤0.05) higher than the peak period of the low- (37.4 ± 8.7 m min^{-1}; d = 1.3) and moderate-activity group (47.4 ± 10.0 m min^{-1}; d = 0.8). In the high-activity group, the subsequent 5-min period (25.9 ± 12.0 m min^{-1}) after the peak period was significantly (p ≤0.05) higher compared to the low- (13.9 ± 8.5 m min^{-1}; d = 1.2) and moderate-activity group (17.5 ± 9.7 m min^{-1}; d = 0.8). Furthermore, the high-activity group showed higher (p ≤0.05) values at 10- (30.1 ± 13.4 m min^{-1}) and 15 min (29.6 ± 14.8 m min^{-1}) after the peak period than the low-activity group (17.6 ± 11.3 m min^{-1}; d = 1.0 and 14.3 ± 10.4 m min^{-1}; d = 1.2). However, when the post-peak period values were expressed relative to the peak period no significant differences were found. Figure 1 shows the distance covered (m min^{-1}) with HIR for each activity group. When the 5-min periods following the peak 5-min period are compared with the average distance covered in HIR, the high-activity group shows small differences (d <0.6) with no statistical significance (p ≥0.05).

However, the low-activity group showed a moderate difference in HIR (d = 0.7; CI = 2.3 to 6.6; $p \leq 0.05$) at 5 min and a small difference (d = 0.5; CI = 0.6 to 6.9; $p \leq 0.05$) at 15 min after the peak period compared to the average 5-min period. Similarly, the moderate-activity group also showed a moderate difference in HIR (d = 0.9; CI = 4.4 to 9.8; $p \leq 0.05$) at 5 min after the peak period, but no significant ($d < 0.3$; $p \geq 0.05$) difference was observed after that.

Table 1: Yo-Yo IR1 and match variables (mean ± s) for low- (28 files), moderate- (27 files) and high-activity (28 files) groups.

Variables	Low activity	Moderate activity	High activity	Total	Low *vs* Mod Mean difference (90% CI)	Low *vs* High Mean difference (90% CI)	Mod *vs* High Mean difference (90% CI)
Yo-Yo IR1 (m)	1338 ± 388	1333 ± 445	1422 ± 501	1365 ± 443	4.3 (-272.9 to 281.5)	-84.8 (-359.1 to 189.5)	-89.1 (-366.3 to 188.1)
1st half TD (m)	4201 ± 388^{ab}	4938 ± 136^{ac}	5520 ± 256^{bc}	4886 ± 612	-736.4 (-900.5 to -572.2)^{VL}	-1318.4 (-1481.0 to -1155.8)^{VL}	-582.0 (-746.2 to -417.9)^{VL}
Peak 5-min (m min^{-1})	37.4 ± 8.7^{a}	47.4 ± 10.0^{b}	62.5 ± 25.7^{ab}	49.1 ± 19.6	-10.0 (-19.8 to -0.2)^{M}	-25.2 (-34.9 to -15.4)^{L}	-15.1 (-24.9 to -5.3)^{M}
Post 5-min (m min^{-1})	13.9 ± 8.5^{a}	17.5 ± 9.7^{b}	25.9 ± 12.0^{ab}	19.1 ± 11.2	-3.7 (-9.6 to 2.5)	-12.0 (-18.0 to -5.9)^{L}	-8.4 (-14.5 to -2.3)^{M}
Post 5-min (% of peak)	36.9 ± 22.1	36.6 ± 19.3	44.4 ± 20.6	39.3 ± 20.7	0.3 (-12.0 to 12.6)	-7.5 (-19.8 to 4.9)	-7.8 (-20.2 to 4.7)
Post 10-min (m min^{-1})	17.6 ± 11.3^{a}	22.8 ± 10.4	30.1 ± 13.4^{a}	23.3 ± 12.7	-5.1 (-12.7 to 2.5)	-12.4 (-20.0 to -5.0)^{M}	-7.3 (-15.1 to 0.5)^{M}
Post 10-min (% of peak)	45.1 ± 23.2	46.3 ± 18.2	52.0 ± 21.9	47.7 ± 21.2	-1.2 (-14.9 to 12.5)	-6.9 (-20.4 to 6.7)	-5.7 (-19.8 to 8.5)
Post 15-min (m min^{-1})	14.3 ± 10.4^{a}	21.1 ± 9.2	29.6 ± 14.8^{a}	22.0 ± 13.3	-6.8 (-15.2 to 1.6)^{M}	-15.3 (-23.4 to -7.2)^{L}	-8.5 (-16.6 to -0.4)^{M}
Post 15-min (% of peak)	38.4 ± 25.8	44.1 ± 19.0	51.4 ± 24.3	45.0 ± 23.5	-5.7 (-22.2 to 10.8)	-13.0 (-28.9 to 2.9)	-7.3 (-23.2 to 8.6)

^{abc} significant (*$P < 0.05$*) differences between corresponding letters. M/L/VL – Moderate/ Large/ Very large/ practical significant effect (d > 0.6/1.2/ 2.0). Yo-Yo IR1 – Yo-Yo Intermittent Recovery test 1; TD – Total distance; Mod – Moderate; CI – Confidence interval

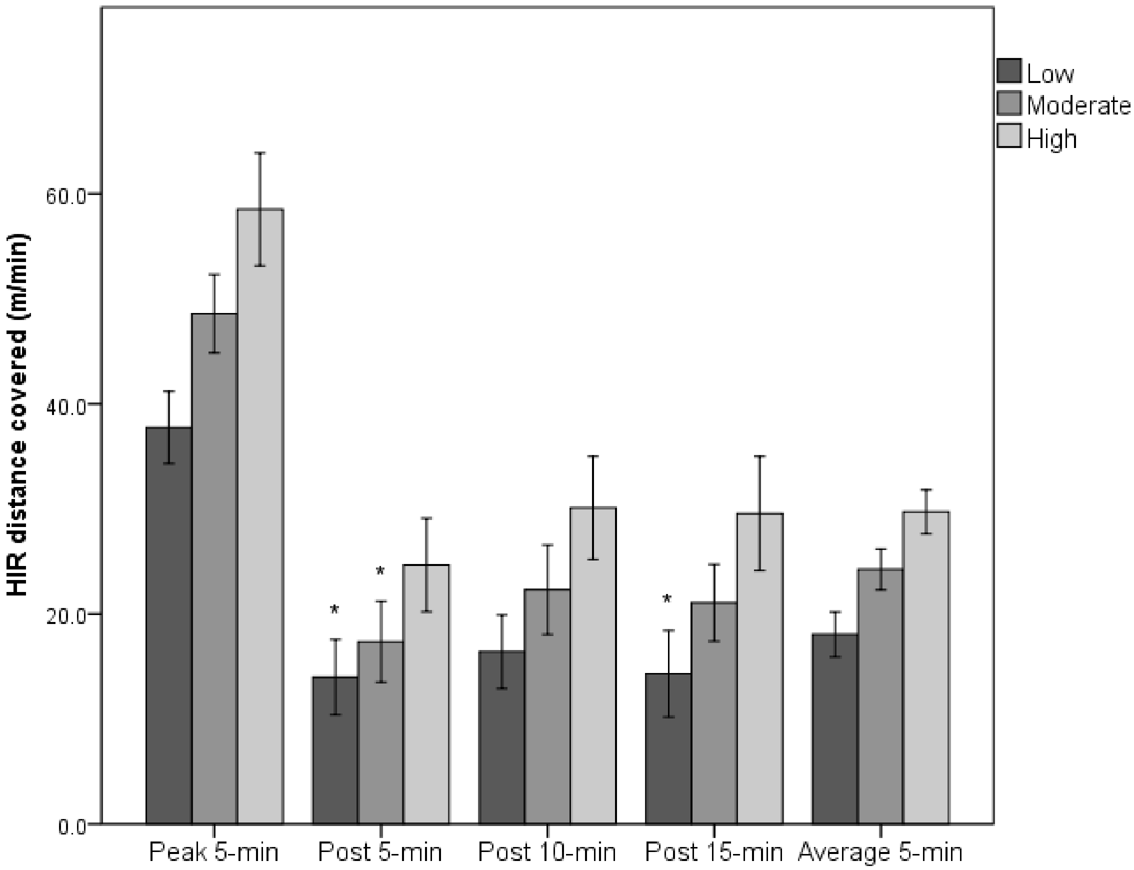

Fig 1: Distance covered (m min^{-1}) in high-intensity running (HIR) for the most intense 5-min period and the subsequent 5-min periods. *Lower ($p \leq 0.05$) than the average 5-min period minus the peak value. Data presented as means and 90% confidence interval.

Figure 2 illustrates the differences between pre-determined 5-min periods for the total distance (m min^{-1}) covered as well as the distance covered (m min^{-1}) with HIR. The moderate-activity group showed no significant ($p \leq 0.05$) differences when comparing the pre-determined 5-min periods between the first and second halves for both total distance covered and HIR. However, the high-activity group showed a moderate ($d > 0.6$; $p \leq 0.05$) to large ($d > 1.2$; $p \leq 0.05$) decline in distance covered between the first 15 min of the second half (103.9 ± 25.5 m min^{-1}) compared to the first 15 min of the first half (122.5 ± 18.8 m min^{-1}). They also showed a small ($d > 0.2$; $p \leq 0.05$) to moderate ($d > 0.6$; $p \leq 0.05$) decline in HIR during the first 10 min of the second half (25.7 ± 12.0 m min^{-1}) compared to the corresponding period in the first half (34.1 ± 14.1 m min^{-1}). Furthermore, the high-activity group showed a moderate ($d > 0.6$; $p \leq 0.05$) decline in distance covered during the 70–75th minute compared to the 25–30th minute (105.3 ± 23.1 m min^{-1} *vs* 120.1 ± 18.0 m min^{-1}) and a small ($d > 0.2$; $p \leq 0.05$) decline during the last 5-min period of the second half compared to the first half (102.3 ± 25.7 m min^{-1} *vs* 116.2 ± 29.2 m min^{-1}). The low-activity group showed a small (d >0.2; p ≤0.05) decline in distance covered during the first 5 min of the second half (76.3 ± 23.6 m min^{-1}) compared to the first half (87.7 ± 17.7 m min^{-1}). Conversely the low-activity group showed a small (d >0.2; p ≤0.05) to moderate (d >0.6; p ≤0.05) increase in distance covered during the last 10 min of the second half (95.7 ± 17.9 m min^{-1}) compared to the first half (84.4 ± 17.4 m min^{-1}) as well as a moderate (d >0.6; p ≤0.05) increase in HIR during the 80–85th minute compared to the 35–40th minute (19.9 ± 11.2 m min^{-1} *vs* 13.3 ± 8.7 m min^{-1}).

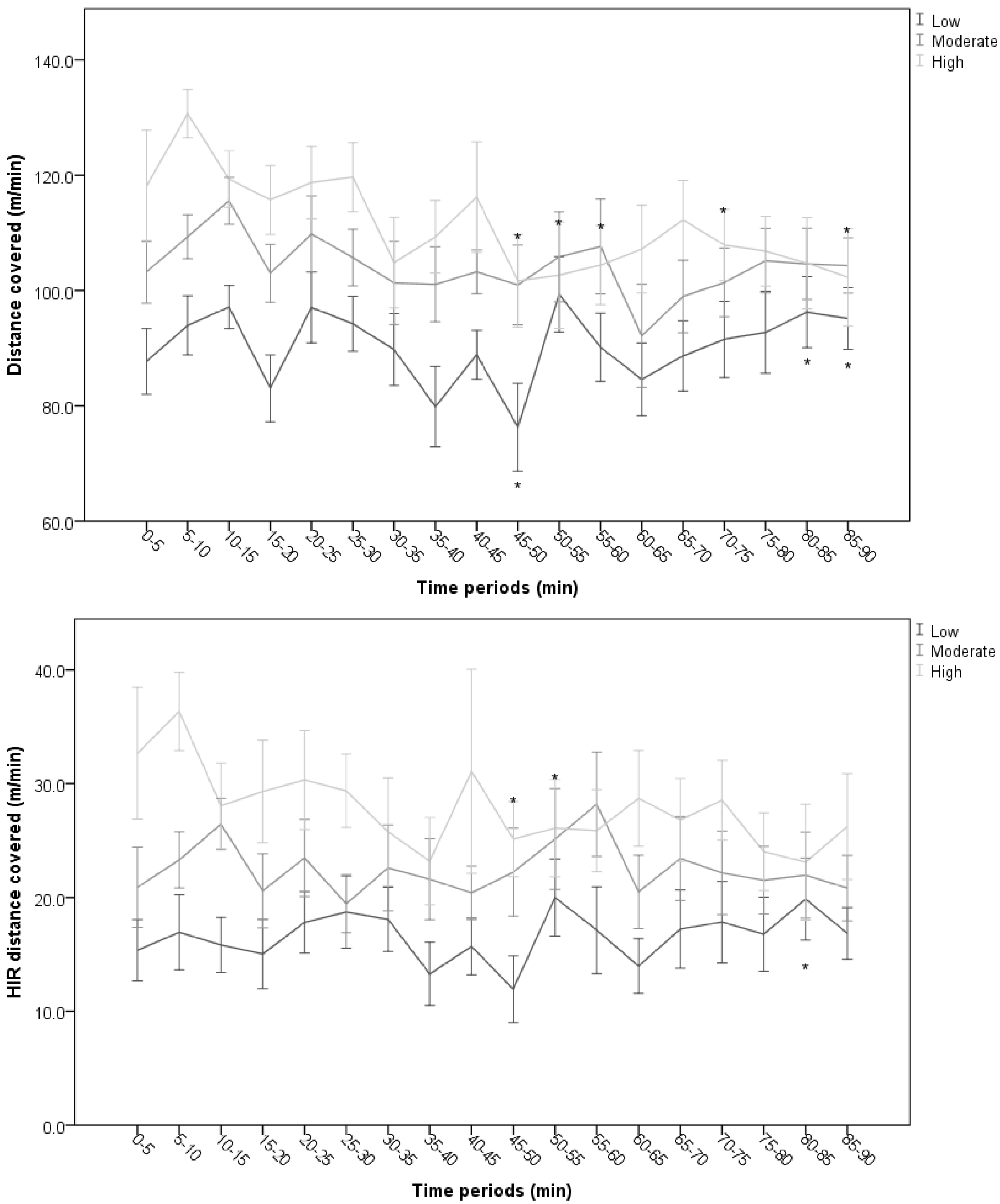

Fig 2: Total distance (m min^{-1}) and high-intensity running (HIR) distance (m min^{-1}) covered by players during pre-determined 5-min periods. *Significantly (p ≤0.05) different from corresponding 5-min period in the first half.

4. Discussion

This study quantified HIR performance in rolling 5-min periods to determine the fatigue rate of university-level soccer players during match-play. In addition, we determined whether training status had an influence on the way university-level soccer players regulated HIR during match-play. One of the main findings of the study is that first-half match activity levels had a significant influence on fatigue after the most intense 5-min period as well as on second-half match performance. What this finding suggests is that performance during the first half had a significant effect on the fatigue patterns during the match. Furthermore, a rather surprising finding was that Yo-Yo IR1 determined training status had no influence on any of the HIR or fatigue-related variables.

To the authors' knowledge this is the first study to have used a 10 Hz GPS and rolling 5-min periods to determine the most intense periods in semi-elite competitive soccer matches and the possible influence of these periods on the subsequent 15 min. In this study the high-activity group (62.5 m min^{-1}) had a significantly higher peak 5-min period than the low- (37.4 m min^{-1}) and moderate-activity (47.4 m min^{-1}) groups. The first 5-min period after the peak period was also significantly higher for the high-activity group (25.9 m min^{-1}) than the low- (13.9 m min^{-1}) and moderate-activity (17.5 m min^{-1}) groups. At 10 and 15 min after the peak period, the high-activity group's movement speeds (30.1 m min^{-1} and 29.6 m min^{-1}) were still higher than that of the low-activity group (17.6 m min^{-1} and 14.3 m min^{-1}). However, when these post-5-min periods were expressed relative to the peak period of each group no significant differences were found. A comparison between the 5-min periods after the most intense 5-min period and the average 5-min period (excluding the peak period) for each group revealed that none of the high-activity group's recovery periods differed significantly from that of the average 5-min period. On the other hand, the low-activity group showed significantly lower HIR values for both the post-5-min and post-15-min periods, whereas the moderate-activity group only showed significantly lower values at the post-5-min period.

Although several researchers have also observed that there is a significant decline in the post-5-min period after the most intense period,[8,13,14,16] none of them differentiated between activity levels in the first half. However, Bradley and Noakes[16] investigated the post-10- and post-15-min periods and found no significant decreases in HIR compared to the average 5-min period. It is important to note that these studies were performed on professional soccer players whereas our study focused on university-level soccer players. Despite these differences in participation levels the peak 5-min period (49.1 m min^{-1}) for all groups reported in this study is similar to the values reported by Bradley et al.[13] (46.2 m min^{-1}) and Bradley et al.[14] (48.2 m min^{-1}), but the first 5-min period after the peak period (19.1 m min^{-1}) in this study is slightly lower than the values from those studies

(25.2 m min^{-1} and 22.8 m min^{-1}). In this regard Mohr et al.[26] suggested that the temporary decline in HIR during halves was due to the accumulation of potassium which causes electrical disturbances and negatively influences force production.

When comparing performances between the first and second half, the moderate-activity group were able to maintain the same distance and HIR distance throughout the entire match without any significant differences between 5-min periods. However, the low-activity group showed a decline in distance covered during the first 5 min of the second half. Interestingly though, the low-activity group covered a higher average distance during the final 10 min and a higher HIR distance during the 80th min period of the match. In contrast, the high-activity group showed a decline in distance covered during the first 15 min of the second half as well as a decrease in HIR during the first 10 min of the second half. Additionally the same group (high-activity group) also displayed a decrease in distance covered during the 70–75th min and 85–90th min periods. These findings are very similar to those of Bradley and Noakes[16] who reported that the high-activity group showed significant decreases in distance covered and HIR during the first 10 min of the second half. They also reported declines in distances covered during the 70th and 85th minute for the high-activity group. However they also reported declines in distance covered during the first 10 min of the second half for the low- and moderate-activity groups whereas only the low-activity group showed significant declines in our study. Even though Mugglestone et al.[5] did not differentiate between the activity levels of players during the first half, they also reported declines in HIR during the first 5 min of the second half in semi-professional matches.

The decline in match performance during the first 10 minutes of the second half could be attributed to the fall in muscle temperature during the half-time break. Mohr et al.[27] found a significant correlation between muscle temperature after the half-time break and HIR performance during the second half. The results of our study also support notions by others that players may pace themselves during matches with an end-spurt occurring towards the end of a match.[7,16,28] The low-activity group from this study was able to increase the distance covered during the last 10 min of the match. However, caution is needed before attributing these results to fatigue or pacing, since several contextual factors may influence these results including the tactical role of players and the actual time the ball is in play.[2] Furthermore, high-intensity activities could be underestimated as accelerations, and decelerations were not taken into account.

In this study Yo-Yo IR1 performance showed no correlation with any of the locomotor variables. This is in strong contrast to previous studies which reported strong correlations with HIR performance in matches.[17,18] Furthermore, Mohr et al.[8] reported a significant correlation (r = 0.51; $p \leq 0.05$) between Yo-Yo IR1 performance and the distance covered in

HIR during the last 15 min of a match. It must, however, be noted that participants' Yo-Yo IR1 values were very similar and the standard deviation very small. It is therefore possible that the homogeneity of Yo-Yo IR1 results had led to smaller correlation values.[29] However, it is worth noting that even though there was no significant correlation between Yo-Yo IR1 and the activity profiles, the Yo-Yo IR1 results were better for players in the high-activity group. This suggests that although Yo-Yo IR1 and the locomotor variables were not directly associated with each other, the Yo-Yo IR1 performance contributes to a better first-half performance.

5. Conclusion

To conclude, this is the first study to have used a 10 Hz GPS and rolling 5-min periods to determine the most intense periods in competitive soccer matches and the possible influence of these periods on subsequent activity levels during the next 5-min periods. Furthermore, this is the first study to examine the relationships between training status, HIR performance and fatigue in semi-elite soccer players during competitive matches. We found no relationship between Yo-Yo IR1 performance and any of the HIR running and recovery variables, but it seems that Yo-Yo IR1 performance contributes to a better first-half performance. Also, first-half activity profiles had a significant impact on recovery after the most intense 5-min period as well as second-half performance. This suggests a degree of transient fatigue. Our study also supports the possibility that players pace themselves during matches with an end-spurt occurring towards the end of a match. However, future studies should take into account the contextual factors which may influence the match performance of players.

Practical implications

- Rolling 5-min periods and GPS variables can be used to determine the running performance and fatigue patterns of university-level soccer players during competitive matches.
- Conditioning programs should be set up in such a way that it prepares players to maintain HIR activities after very intense periods of play during soccer matches.
- The distance players covered during the first half affects not only the amount of total distance covered in the second half, but also the distance covered in HIR. Conditioning coaches should therefore enable players to maintain their movement rates during the entire duration of a match.

Acknowledgements

The authors would like to thank the players and coaches for their participation in this research project. There was no financial support received for this study.

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CHAPTER 4

4 THE USE OF HEART RATES AND YO-YO INTERMITTENT RECOVERY TEST-DERIVED THRESHOLD VALUES TO DETERMINE THE POSITIONAL, INTERNAL MATCH LOADS OF UNIVERSITY-LEVEL SOCCER PLAYERS

Title: The use of heart rates and Yo-Yo intermittent recovery test-derived threshold values to determine the positional, internal match loads of university-level soccer players

Running title: Internal match loads of university-level soccer players

Keywords: heart rate, football, match intensity, aerobic testing

Abstract

The aim of the study was to use heart rates and the Yo-Yo Intermittent Recovery test level 1 (Yo-Yo IR1)-derived thresholds to determine the internal match loads of university-level soccer players. Players completed a Yo-Yo IR1 while wearing a portable gas analyser. Heart rates that corresponded to the first and second ventilatory thresholds were used to classify the heart rates into low- (LI HR zone), moderate- (MI HR zone) and high-intensity zones (HI HR zone). During 12 soccer matches it was found that attackers (n = 17) spent more total time in the LI HR zone (3386 s; 62%; $P < 0.05$) than defenders (2155 s; 40%; n = 36) and midfielders (2425 s; 42%; n = 41). The attackers spent less total time in the HI HR zone (260 s; 4%; $P < 0.05$) compared to the defenders (964 s; 15%). Midfielders (2444 s; 44%) and defenders (2364 s; 41%) spent more total time in the MI HR zone compared to attackers (1854 s; 44%). This study is the first to show that the more sport-specific Yo-Yo IR1 test can be used to determine individual, physiologically defined intensity zones to describe positional differences in the internal match loads of soccer players.

Introduction

Soccer is one of the most popular sports in the world and is played both by men and woman at amateur and professional level (Stølen, Chamari, Castagna & Wisløff, 2005; Tessitore et al., 2005). The popularity of the sport as well as the substantial financial rewards offered for success (Reilly, Bangsbo & Franks, 2000), have highlighted the importance of obtaining accurate, reliable and objective data with regard to the loads placed on players during match-play (Eniseler, 2005). Until recently, the primary methods that have been employed to determine the internal match loads of team sport players have included rating of perceived exertion (RPE), blood lactate concentration and heart rate (HR) monitoring (Eniseler, 2005; Impellizzeri, Rampinini, Coutts, Sassi & Marcora, 2004) as well as the combined use of heart rates and graded maximal test values (Sparks & Coetzee, 2013). However, although these methods provide valuable insight into the internal load experienced by players during match-play, certain methodological flaws exist which may negatively influence the accuracy of match analysis results (Sparks & Coetzee, 2013).

Blood lactate sampling during matches are dictated by stoppages in play and in cases where the time span after high-intensity bouts are too long the blood lactate will be metabolised before measurements are taken, which will then not reflect the true demands of match-play (Duthie, Pyne & Hooper, 2003). Also, although RPE is seen as a valid method for quantifying exercise demands (Eniseler, 2005), it is difficult to collect RPE scores at regular intervals during a competitive soccer match. HR analyses are therefore regarded as a more accepted method for the determination of soccer players' internal match loads, especially when HR is expressed as a function of maximum HR (HR_{max}) (Alexandre et al., 2012). Findings with regard to average heart rates during university-level soccer matches show that midfielders obtained the highest average HR (173 bpm) compared to attackers (171 bpm) and defenders (156 bpm) (Ali & Farrally, 1991). Similarly, Stroyer, Hansen and Klausen (2004) reported an average HR of 172 bpm for youth soccer defenders and a value of 167 bpm both for midfielders and attackers. Alexandre et al. (2012) concluded that, independent of playing level, soccer players spent 65% of the total match time between 70 and 90% of the HR_{max}.

However, despite the availability of studies that have analysed the match HR results of soccer players, researchers suggest that sport practitioners should use individualised HR zones when describing the HR responses of players during training and competition (Alexandre et al., 2012). In this regard Eniseler (2005) determined the heart rates that corresponded to the 2 and 4 mM blood lactate concentrations as obtained from a 20-m shuttle run test, to show that on average 37% of the match was spent in the HR zone that corresponded to the heart rates between the 2 and 4 mM blood lactate concentrations. Furthermore, they observed that 50% of the match time was spent in the HR zone which corresponded to the blood lactate concentration of above 4 mM. Although the above-mentioned method allowed researchers to determine individualised HR zones, the accuracy of this method can be questioned. In this regard Faude, Kindermann and Meyer (2009) showed that the use of the 4 mM threshold value could lead to an underestimation of the endurance capacity of anaerobically trained sport participants.

Another individualised analysis method uses cardiorespiratory exercise testing by means of a graded maximal treadmill test in order to determine the ventilatory threshold (VT) and the respiratory compensation point (RCP) of sport participants (Abt & Lovell, 2009; Sparks & Coetzee, 2013). Abt and Lovell (2009) used a similar method for determining the running speed that corresponded to the VT to categorise soccer match-play movements into high-intensity movements and found that players covered an average distance of 2 258 m at high intensities during a soccer match. Sparks and Coetzee (2013) also applied this method for determining the HR intensity zones of team sport participants and revealed that Rugby Union players spent 44% of the match time in the high-intensity zone (HIZ) (170–185 bpm), 34% in the moderate-intensity zone (MIZ) (153–169 bpm) and only 23% in the low-intensity zone (LIZ) (141–152 bpm).

However, in view of the fact that the muscle recruitment patterns and energy demands during a rugby match are different from those of a treadmill test, a standard incremental treadmill test may not be the most suitable method for determining the HR intensity zones for analysing team sport loads (Sparks & Coetzee, 2013). The Yo-Yo Intermittent Recovery Test level 1 (Yo-Yo IR1) has been widely applied in many team sports to evaluate players' abilities to repeatedly perform high-intensity exercise (Bangsbo, Iaia & Krustrup, 2008) and may possibly serve as a more sport-specific field test for determining different HR intensity zones. In this regard, Castellano and Casamichana (2010) used the Yo-Yo IR1 to determine the following HR intensity zones for analyses of beach soccer matches: < 75% HR_{max}, 76–84% HR_{max}, 85–89% HR_{max} and > 90% HR_{max}. They reported the mean HR during the match to be 86.5% of the HR_{max} and showed that players spent 59.3% of the total match time at >90% HR_{max} (Castellano & Casamichana*,* 2010). Krustrup et al. (2003) also found significant ($P < 0.05$) correlations between Yo-Yo IR1 results and the amount of high-intensity running ($r = 0.71$) and total distance covered ($r = 0.58$) during a soccer match. These findings suggest that the Yo-Yo IR1 test shows promise to be used as a valid sport-specific field test to determine the ventilatory thresholds of individual soccer players as well as heart rates that correspond to these thresholds, in order to determine the internal match loads of each player. Therefore the aim of the present study was to use heart rates and the Yo-Yo IR1-derived threshold values for determining the positional, internal match loads of university-level soccer players. The accurate quantification of university-level soccer match loads will enable coaches and sport scientists to develop conditioning programs that prepare players for the specific demands of match-play.

Methods

Participants

Participants consisted of a selected group of 10 male soccer players that played for the first team of one of the universities in the North West Province of South Africa. Players' age, body stature and mass (mean ± *s*) were 22.6 ± 2.5 years; 173.4 ± 7.2 cm and 64.6 ± 9.1 kg respectively. The players were divided into three positional groups, namely attackers (17 files), midfielders (41 files) and defenders (36 files). Goalkeepers were excluded from the study. These players were tested during the competition phase of their periodization cycle, during which they played 16 matches. Players trained five times a week for 1.5 hours per training session and played at least one league match per week. The team competed in the provincial A-league. The objectives of the study were explained to the players, after which they completed an informed consent form. Ethical approval was granted by the Health Research Ethics Committee of the Faculty of Health Sciences of the institution where the research was conducted (NWU-00200-14-A1). The study was 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 of South Africa.

Procedure

Twelve A-league matches were analysed. For the players' data to be included in the study, they had to spend at least 50% of the match on the field, they needed to complete the Yo-Yo IR1 until exhaustion at least two weeks before or after the analysed matches and they had to be injury free at the time of testing. In other words in cases where players for some or other reason left the field before 50% of game time elapsed, the match data for that participant was excluded. The heart rates of the starting line-up were recorded *via* Fix Polar Heart Rate Transmitter Belts (Polar Electro, Kempele, Finland), at 5-second intervals during the course of twelve matches.

Yo-Yo Intermittent Recovery Test Level 1

All players in this study were familiar with the Yo-Yo IR1 test and had performed it at least once before commencement of the study. The Yo-Yo IR1 test was performed according to the method of Bangsbo, Mohr, Poulsen, Perez-Gomez and Krustrup (2006). The Yo-Yo IR1 was chosen as being the preferred test for this study in view of the fact that the test showed significant correlations (r = 0.71; $P < 0.05$) with the amount of high-intensity running during a soccer match (Krustrup et al., 2003). The Yo-Yo IR1 has been widely applied in many team sports to evaluate players' abilities to repeatedly perform high-intensity exercise (Bangsbo et al., 2008). A significant correlation between maximal aerobic oxygen uptake ($\dot{V}O_{2max}$) and

Yo-Yo IR1 results ($r = 0.70$, $P < 0.05$) also demonstrate that the Yo-Yo IR1 is a valid exercise test for the determination of players' $\dot{V}O_{2max}$ (Bangsbo et al., 2008).

The test was conducted on a flat, clearly marked 20-m stretch of a grass soccer field. Players were wearing their soccer boots during the test. Players were required to run back and forth on a 20-m track and pace themselves so that the arrival at the end of the 20-m stretch coincided with the signal that was emitted from a commercially available pre-recorded compact disc (CD) (Bangsbosport.com, Bangsbosport Aps, Espergaerde, Denmark). Players were required to cross the marked lines at either end of the 20-m stretch with one foot as the signal sounded from the CD. Each player received a brief 10-s active break after each 40 m (2 x 20 m) run during which they walked back and forth over a 5-m stretch. The test started at 10 $km.h^{-1}$ and the running speed was progressively increased until test termination. The test was terminated if players voluntarily dropped out or when players could not make it to either end marks of the 20-m distance within the given signal time in two successive shuttles. The players were verbally encouraged to perform maximally during each assessment. Prior to each Yo-Yo IR1, the players performed a warm up of 10 minutes consisting of jogging and dynamic stretching exercises.

Players performed the Yo-Yo IR1 while wearing a portable gas analyser apparatus (Metamax 3B, Cortex, Leipzig, Germany) and a Fix Polar Heart Rate Transmitter Belt (Polar Electro, Kempele, Finland), which were used to sample expired air and HR continuously. The rate of oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), minute ventilation ($\dot{V}_E$), respiratory exchange ratio (RER) and HR for each 5-second period were determined. The portable gas analyser was calibrated with standard gases before commencement of the test. The criteria for reaching $\dot{V}O_{2max}$ was set as follows: a respiratory exchange ratio-value higher that 1.15 at test termination; oxygen consumption ceased to rise and reached a plateau or began to fall even though the work rate continued to increase, or the maximal age-specific HR was reached (Davis, 2006; McArdle, Katch & Katch, 2010). The MetaMax 3B portable gas analyser apparatus is regarded to be a reliable and valid gas analyser, slightly overestimating $\dot{V}O_2$, $\dot{V}CO_2$ and $\dot{V}_E$ by approximately 4%, 7%, and 4%, respectively compared to an automated Douglas bag system (Vogler, Rice & Gore, 2010). The MetaMax3B also yields excellent reproducibility with typical errors of between 2 and 3% for $\dot{V}O_2$, $\dot{V}CO_2$ and $\dot{V}_E$ (Vogler et al., 2010).

Determination of ventilatory and heart rate thresholds

The following two physiological gas exchange points were also identified to determine the different HR zones for classification of the match-obtained variables: VT was determined using the criteria of an increase in $\dot{V}_E/\dot{V}O_2$ with no increase in $\dot{V}_E/\dot{V}CO_2$ and departure from the linearity of $\dot{V}_E$ (Chicharro, Hoyos & Lucia, 2000). The RCP was taken as the point which corresponded to an increase in both $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$ (Chicharro et al., 2000). VT and RCP were visually detected by two independent experienced observers. This approach has previously been shown to be reliable (Weston & Gabbett, 2001). Weston and Gabbett (2001) found a high intra-evaluator reliability (r = 0.91–0.97, $P <0.0001$) for repeated determinations of VT1 and VT2 (RCP). The different gas exchange phases were used to determine the heart rates that corresponded to the three exercise intensities (Chicharro et al., 2000): Heart rates that correspond to the exercise intensities below VT were classified as low-intensity (LI) heart rates; heart rates between VT and RCP as moderate-intensity (MI) heart rates; and heart rates above RCP were classified as high-intensity (HI) heart rates.

Statistical analysis

Ambient temperature was monitored through the South African Weather Service during matches to enable the researchers to correct for temperature fluctuations during statistical analyses of the data. The mean temperature throughout the twelve matches was 19.1 ± 6.1˚C. The HR values each player obtained during the different matches were categorised into the three intensity zones (low, moderate and high) according to the Yo-Yo IR1-determined threshold values. The absolute total time (90 min including injury time) spent in the different zones as well as the time expressed as a percentage of the total match time (excluding the time before the matches and half-time) were firstly calculated. The descriptive statistics of these variables were determined next. A linear mixed model analysis was used to investigate positional differences with an autoregressive 1 (AR1) structure, using IBM SPSS Statistics (version 21.0.0.0). The players were entered as subjects and playing positions were entered as fixed effects into the model. Temperatures measured during each match were inserted as a co-variant to correct for fluctuations in temperature. However, it was apparent from the analysis that ambient temperature did not influence any of the performance variables. A Bonferroni post-hoc test was subsequently performed to determine significant differences between positions. The p-value was set at $P \leq 0.05$. Furthermore, effect sizes (ES) and 90% confidence intervals (CI) were calculated to determine the practical significance of differences between positional groups. Effect sizes (ES) were interpreted using a scale of magnitudes (Cohen, 1988) comprising small

(>0.1), moderate (>0.3), large (>0.5) values and augmented (Hopkins, Marshall, Batterham & Hanin, 2009) to include very large (>0.7) and extremely large (>0.9) values.

Results

The results from the Yo-Yo IR1 are presented in Table I. The players covered an average distance of 1 376 m and obtained an average $\dot{V}O_{2max}$ of 57.6 ml.kg^{-1}.min^{-1} at an average HR_{max} of 192 bpm during the Yo-Yo IR1. The average HR for the MI HR zone (VT HR) started at 162 bpm (84% of HR_{max}) and the average HR for the HI HR zone (RCP HR) at 184 bpm (96% of HR_{max}).

Table I: Results of the Yo-Yo IR1 for defenders (n = 7), midfielders (n = 11) and attackers (n = 4).

Variables	Defenders	Midfielders	Attackers	Total
Yo-Yo IR1 HR_{max} (bpm)	191 ± 7	192 ± 7	193 ± 7	192 ± 7
Yo-Yo IR 1 distance (m)	1274 ± 338	1406 ± 508	1470 ± 429	1376 ± 433
$\dot{V}O_{2max}$ (ml.kg.$^{-1}$·min^{-1})	57.3 ± 3.6	58.0 ± 5.4	57.0 ± 10.2	57.6 ± 5.7
VT HR (bpm)	161 ± 9	160 ± 8.5	169 ± 10	162 ± 9
VT HR (%)	84.2 ± 4.5	83.4 ± 4.5	87.5 ± 4.4	84.4 ± 4.5
RCP HR (bpm)	182 ± 9	184 ± 6	188 ± 6	184 ± 7
RCP HR (%)	95.0 ± 4.4	96.0 ± 1.5	97.5 ± 1.1	96.0 ± 2.8

VT HR – Heart rate at the ventilatory threshold; RCP HR – Heart rate at the respiratory compensation point; $\dot{V}O_2$ - Oxygen consumption; $\dot{V}O_{2max}$ - Maximum oxygen consumption; Yo-Yo IR1 – Yo-Yo Intermittent Recovery Test 1; bpm – beats per minute

Table II contains the internal load variables experienced during match-play for the different positional groups. All the positional groups had similar average heart rates during the matches with heart rates of 159 bpm, 159 bpm, and 155 bpm for defenders, midfielders and attackers respectively. Notably, attackers spent more time in the LI HR zone (3386 s ± 991; 62% ± 18 of total time; $P < 0.05$) than defenders (2155 s ± 1133; 40% ± 21 of total time; d = 1.1) and midfielders (2425 s ± 1158; 42% ± 22 of total time; d = 0.9). Moreover the attackers spent less time in the HI HR zone (260 s ± 360; 4% ± 6 of total time; $P < 0.05$, d ≥ 0.8) than the defenders

(964 s ± 936; 15% ± 16 of total time). Although midfielders only spent statistically ($P < 0.05$) more relative time (44% ± 17 of total time) in the MI HR zone than attackers (31% ± 13 of total time), midfielders (2444 s ± 828; 44% ± 17 of total time; $d \geq 0.8$), and defenders (2364 s ± 676; 41% ± 13 of total time; $d = 0.7$) spent practically more time in the MI HR zone than did attackers (1854 s ± 692; 44% ± 17% of total time).

Table II: The internal match load related variables (mean ± s) for defenders (36 files), midfielders (41 files) and attackers (17 files).

Variables	**Defenders**	**Midfielders**	**Attackers**	**All positions**	**Att *vs* Def Mean difference (90% CI)**	**Def *vs* Mid Mean difference (90% CI)**	**Att *vs* Mid Mean difference (90% CI)**
HR_{mean} (bpm)	159 ± 11	159 ± 9	155 ± 11	158 ± 10	-4 (-11 to 3)	0 (-5 to 5)	-4 (-10 to 2)
LI HR time (s)	2155 ± 1133[a]	2425 ± 1158[b]	3386 ± 991[ab]	2510 ± 1196	1231 (470 to 1993)[EL]	-270 (-921 to 381)	962 (171 to 1752)[VL]
LI HR relative time (%)	39.8 ± 21.0[a]	42.1 ± 21.5[b]	61.7 ± 18.4[ab]	44.8 ± 22.1	22 (9 to 35)[EL]	-2 (-13 to 8)	20 (7 to 33)[VL]
MI HR time (s)	2364 ± 676	2444 ± 828	1854 ± 692	2285 ± 761	-510 (-1013 to -7)[L]	-80 (-1438 to 1278)	-590 (-3189 to 2009)[VL]
MI HR relative time (%)	40.6 ± 13.4	44.3 ± 16.7[a]	30.5 ± 12.6[a]	40.4 ± 15.5	-10 (-20 to -1)[L]	-4 (-11 to 4)	-14 (-23 to -5)[VL]
HI HR time (s)	964 ± 936[a]	640 ± 730	260 ± 360[a]	701 ± 811	-704 (-1233 to -174)[VL]	324 (-129 to 777)	-380 (-930 to 170)
HI HR relative time (%)	14.9 ± 16[a]	9.6 ± 11.9	4.0 ± 6.0[a]	10.6 ± 13.4	-11 (-19 to -3)[VL]	5 (-1 to 12)	-6 (-14 to 3)

[ab] significant ($P < 0.05$) differences between corresponding letters. L/VL/EL – Large/ Very large/ Extremely large practical significant effect (d > 0.5/ 0.7/ 0.9). HI – High-intensity; HR – Heart rate; LI – Low-intensity; MI – Moderate-intensity; Att – Attackers; Def – Defenders; Mid – Midfielders; CI – Confidence Intervals.

Discussion

To the authors' knowledge this is the first study to use heart rates and the Yo-Yo IR1-derived threshold values to determine the internal match loads of university-level soccer players. Overall the results suggest that this method can be used successfully to calculate soccer players' internal match loads. The application of this method showed that university-level players spent most of their match time in the LI HR zone (44.8%) followed by the MI HR zone (40.4%) and HI HR zone (10.6%). As mentioned previously, Eniseler (2005) used lactate reference values to categorise heart rates into low-, moderate- and high-intensity HR zones. Eniseler (2005) observed remarkably similar values for the total time spent in the MI HR zone (37%) by professional soccer players compared to the values of players in this study (40%). However, in our study players spent more relative time in the LI HR zone (45%) and considerably less time in the HI HR zone (11%) than did the players in the study of Eniseler (2005) (14% and 50%). Impellizzeri et al. (2006) used a threshold of 95% of HR_{max}, which is similar to the HI HR zone (96% of HR_{max}) in this study, to investigate the time soccer players spent in an HI HR zone during a match. They reported a value of 226 s which is much lower that the value of this study (701 s). However, it is important to note that the matches in their study were 60-min matches, whereas the match time in the current study was 90 min (excluding injury time). Therefore players in the current study had much more time to spend in the HI HR zone.

The positional analyses revealed that attackers spent significantly ($P < 0.05$) more time in the LI HR zone (3 386 s ± 991; 62% ± 18 of total time) than defenders (2155 s; 40% of total time; d = 1.1) and midfielders (2425 s; 42% of total time; d = 0.9). They also spent significantly ($P < 0.05$) less time in the HI HR zone (260 s; 4% of total time; d ≥ 0.8) than the defenders (964 s; 15% of total time). Although midfielders only spent statistically ($P < 0.05$) more relative time (44% of total time) in the MI HR zone when than attackers (31% of total time), midfielders (2444 s; 44% 17 of total time; d ≥ 0.8) and defenders (2364 s; 41% of total time; d = 0.7) spent practically more time in the MI HR zone than attackers (1854 s; 44% of total time). The use of a defensive playing pattern (4-5-1) during matches may partly explain why defenders spent significantly more time in the HI HR zone than attackers, with attackers spending most of their match time in the LI HR zone. These results could be ascribed to a more crowded midfield which may allow attackers to remain in the upper part of the playing field for longer periods of time while they wait to receive the ball from the midfield.

The three positional groups (defenders, midfielders and attackers) achieved more or less similar average match heart rates: 159 bpm, 159 bpm, and 155 bpm respectively. Stroyer (2004) found the average match HR for youth defenders to be 167 bpm compared to attackers and midfielders who both obtained an average HR of 172 bpm. However, Ali and

Farrally (1991) reported a lower average HR of 156 bpm for university-level soccer defenders in their study, whereas the midfielders and attackers obtained an average HR of 173 bpm and 171 bpm, respectively.

For purposes of this study the Yo-Yo IR1-derived ventilatory thresholds were used to divide each player's match heart rates into LI, MI and HI HR zones according to each player's VT and RCP. The results of this categorisation showed that the MI HR zone started at 84% of the HR_{max} or 162 bpm and the HI HR zone at 96% of the HR_{max} or 184 bpm. Although these relative thresholds are higher than the thresholds of 80% and 90% of HR_{max} suggested by Bangsbo (2003), the absolute HR threshold values are very similar (160 and 180 bpm). In contrast, Abt and Lovell (2009) observed lower relative and absolute heart rates for the HI HR zone (93% of the $HR_{max,}$ 172 bpm) of soccer players in their study. The use of a laboratory-based maximal incremental treadmill test instead of a field-based maximal test for determining the HI zone threshold, may in part explain the differences in absolute and relative heart rate results (Abt & Lovell, 2009). The Yo-Yo IR1 consists of repeating a set distance, pivoting and changing direction while constantly accelerating and decelerating compared to the movements during treadmill running which are continuous, forward running at constant speeds. The muscle recruitment patterns and energy demands during the Yo-Yo IR1 are therefore likely to be higher (as indicated by higher absolute and relative heart rates) than those of the treadmill test.

Researchers agree that laboratory testing should be used as a tool for evaluating general fitness and not for sport-specific fitness (Svensson & Drust, 2005) as the continuous nature of laboratory tests do not simulate the movement patterns of soccer (Meckel, Machnai & Eliakim*,* 2009). Bradley et al*.* (2011) also pointed out that most tests for determining $\dot{V}O_{2max}$ are continuous in nature whereas soccer is intermittent in nature and consists of bouts of high-intensity activities interspersed by low-intensity activities. The Yo-Yo IR field test may therefore serve as a more soccer sport-specific test for determining the $\dot{V}O_{2max}$ and different HR intensity zones of soccer players and was therefore chosen as the preferred test for this study.

The $\dot{V}O_{2max}$ achieved by players during execution of the Yo-Yo IR1 was similar (58 $ml.kg.^{-1}min^{-1}$) to the value reported by Abt and Lovell (2009) (59 $ml.kg.^{-1}min^{-1}$). Furthermore, players in this study achieved their RCP at a higher percentage of $\dot{V}O_{2max}$ (96%) than the players in the study of Abt and Lovell (2009) (93%), possibly because of low $\dot{V}O_{2max}$ values which gave rise to higher RCP values when expressed as a percentage of

$\dot{V}O_{2max}$. This could also explain why players spent less time in the HI HR zone than players of other studies. In this regard, a review by Stølen et al. (2005) concluded that the $\dot{V}O_{2max}$ values of soccer players varied between 50 and 75 $ml.kg.^{-1}min^{-1}$, which places the $\dot{V}O_{2max}$ values of players in this study at a lower range. In view of the fact that $\dot{V}O_{2max}$ is a measure of cardiovascular fitness (Stølen et al., 2005), players' fitness levels could be classified as low, which may also explain the difference in relative threshold results compared to values obtained by other researchers.

Conclusion

This study is the first to use a sport-specific test to determine individual, physiologically defined intensity zones to describe the internal match loads of university-level soccer players. Our results show that university-level soccer defenders spend significantly more time in the HI HR zone than attackers. Furthermore, results revealed that attackers spent significantly more time in the LI HR zone than midfielders and defenders. The study highlights the intense nature of soccer matches as players spent the majority of match time near the anaerobic threshold, interspersed with periods of LI activities. University-level soccer players should therefore spend the majority of practice and training time at an average relative HR of 81% of HR_{max}. Furthermore, conditioning coaches should develop training programs to allow defenders and midfielders to spend more time in the HI HR zone than attackers. Finally, our results demonstrate that the Yo-Yo IR1-derived ventilatory threshold values can be used to describe the internal match and training loads of soccer players. However, in order to verify these results, researchers need to apply this method to a wider population of soccer players.

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CHAPTER 5

5 INTERNAL AND EXTERNAL MATCH LOADS OF UNIVERSITY-LEVEL SOCCER PLAYERS: A COMPARISON BETWEEN METHODS

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RUNNING HEAD: INTERNAL AND EXTERNAL MATCH LOADS OF SOCCER PLAYERS

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ABSTRACT

The aim of this study was to compare two different methods of determining the external and internal match loads of university-level soccer players. Thirteen soccer players completed a 40-m maximum speed test and the Yo-Yo intermittent recovery 1 test level 1 (IR1) to determine individualised velocity and heart rate (HR) thresholds. The HR values and GPS data of each player were recorded during five league matches. A large ($r = 0.5$; $p \leq 0.01$) correlation was found between time spent in the low-intensity (LI) velocity zone (LIVZ) (5017 ± 368 s) and the LI HR zone (2891 ± 1086 s). Similarly, there was a moderate ($r = 0.3$; $p \leq 0.01$) to large (r = 0.6; $p \leq 0.01$) correlation between the relative (11.4 ± 3.7%) and absolute time (669 ± 223 s) spent in the moderate-intensity (MI) velocity zone (MIVZ) and the MI HR zone (41.0 ± 16.8% and 2253 ± 752 s). There were no significant correlations ($p \leq 0.01$) between the high-intensity (HI) velocity zones (HIVZ) and the HI HR zone. Furthermore when adjusting for the fitness level of players there were no correlations between the internal and external match loads. Results further indicated moderate to large correlations between the external and internal match loads at low and moderate intensities, but no correlations were found at high intensities. To conclude, results suggest that researchers must use individually determined thresholds to examine both the internal and external loads of soccer matches when conducting match analyses.

KEY WORDS: GPS, heart rate, match analysis, soccer

INTRODUCTION

The better the understanding of the specific loads placed on soccer players during match-play, the more likely suitable training and recovery programs will be developed, which may lead to a decrease in injuries as well as an improvement in performance (29). The load players experience during match-play can be categorized as an external load which will induce a physiological response or an internal load (26). In this regard semi-automated video tracking (9), manual video tracking (11) and global positioning system (GPS) analyses (40) are some of the most popular soccer match analysis methods that have been used over the past decade to determine external match loads. However, several studies have also focussed on internal match loads through the analyses of heart rate (39), blood lactate concentration (20) and the use of gas exchange values during graded maximal tests (37). However, in order to obtain an accurate match load profile of sport participants, researchers and sport scientists need to use methods that allow them to simultaneously analyse both the internal and external match loads of players (2).

Although various methods enable researchers to measure the external match loads of players, literature suggest that GPS analysis is more accurate than manual video tracking and less expensive than semi-automated video tracking (7, 16). In addition to having the capability to accumulate and process large volumes of data very quickly, GPS technology also provides quantitative data on the position, displacement, velocity, decelerations and accelerations of players on the field (18). Researchers that made use of this method found that semi-professional soccer players covered a total match distance of 10 163 m of which 16% (1 626 m) was *via* high-speed running and 3% (305 m) sprints (32). Conversely, Varley et al. (42) concluded that professional soccer players covered an average of 517 m and 93 m, through high-speed running and sprinting respectively during a match. In contrast, Wehbe et al. (45) indicated that professional players covered a distance of 2 258 m in the high-intensity running zone which includes running, high-speed running and sprinting activities.

Even though the above-mentioned technique is of great value to better understand the external match loads of soccer players, researchers use general movement classification categories for all players during GPS match analyses (40, 45). Individual differences in physical capacities and variations in exercise economy may lead to errors in the estimation of movement classifications and exercise intensities when using the same categories for all players (1). Determining each individual player’s maximal speed and using a certain percentage of the maximal speed value for categorising the different players’ movements may provide one solution to this problem (1).

However, even the use of individualised movement categories during GPS analyses does not enable researchers to directly measure individual players' physiological responses (internal load) to different movements (17). Heart rate (HR) monitoring may therefore provide researchers with a clearer picture of the internal match loads of players. In this regard, studies show that the average HR of players ranged between 153 bpm and 164 bpm during matches (19, 20). A further analysis of match heart rates also showed that recreational soccer players' average heart rates changed from 82% of HR_{max} during the first half to 79% of HR_{max} during the second half (19). On the other hand, professional matches showed an average relative HR of 86% and 83% of HR_{max} for the first and second halves respectively (19). Nevertheless, researchers suggest that sport practitioners should make use of physiologically determined individualised heart rate zones when describing the heart rate responses of players during training and competition (2).

One way of determining individualised heart rate zones is by applying a 20-m shuttle run test to obtain the heart rates that correspond to the 2 and 4 mM blood lactate concentrations respectively (20). Eniseler (20) used this method to show that players spent 37% of the soccer match in the moderate-intensity HR zone (2 to 4 mM blood lactate concentration) and 50% of the time in the high-intensity zone (> 4mM blood lactate concentration). In view of the fact that Faude and his colleagues (21) showed that the use of the 4 mM threshold value could lead to an underestimation of anaerobically trained sport participants' endurance capacity, the accuracy of this method can also be questioned. Another individualised analysis method uses expired gas and heart rate analyses to determine the ventilatory threshold (VT) and the respiratory compensation point (RCP) of sport participants during a graded maximal treadmill test (37). Although researchers have not used this method to analyse soccer players, Sparks and Coetzee (37) revealed that Rugby Union players spent 44% of the match time in the high-intensity zone (170–185 bpm), 34% in the moderate-intensity zone (153–169 bpm) and only 23% of the time in the low-intensity zone (141–152 bpm). Differences in the muscle recruitment patterns, energy demands and the type of movements performed between a soccer match and a continuous treadmill running test involving forward running at constant speeds (37) may warrant the use of a sport-specific maximal test to determine players' different HR intensity zones. In this regard Girard et al. (22) proved that a squash-specific field-based test could be used to determine the VT and RCP of squash players. They also identified different HR intensity zones by applying this method (22).

From the above-mentioned background it is clear that current soccer match analysis methods reveal certain methodological flaws which may provide researchers with inaccurate internal and external soccer match load results. Moreover, no attempt has been made to develop, use or compare the results of match analysis methods that allow the simultaneous analyses of both internal and external match loads. Therefore the purpose of this study was to compare the match analysis results of different methods that are aimed at determining the external and internal match loads of a cohort of university-level soccer players. These results may provide sports practitioners with a better understanding of both the amount of external and internal loads players experience during soccer match-play.

METHODS

Experimental approach to the problem

The specific hypothesis under scrutiny was that no significant relationships will exist between the external and internal match loads of university-level soccer players. A selected group, repeated measures experimental research design was used for testing the hypothesis of this study. Subjects were required to complete a 40-m maximum speed test and the Yo-Yo IR1 during a two-week period either before or after each analysed match. The HR values and GPS data of each player were recorded during five league soccer matches.

Subjects

Subjects consisted of a group of 13 male soccer players from a university in the North West Province of South Africa. Players' age, body stature and mass (mean±SD) were: 22.6 ± 2.5 years; 175.3 ± 7.1 cm and 62.9 ± 10.0 kg respectively. Goalkeepers were not included in the study. Players trained five times a week for 1.5 hours per training session and participated in one league match per week. The team competed in the provincial A-league. For the players' data to be included in the study, they were required to spend at least 50% (one half) of the match on the field; they had to complete the maximum speed and fitness test at least two weeks before or after analysed matches and they had to be injury free at the time of testing.

Also, during the fitness test players had to achieve their maximum oxygen uptake ($\dot{V}O_{2max}$) to be included. All players not adhering to these criteria were excluded from the study. The objectives of the study were explained to the players, after which they all completed an informed consent form. Ethical approval was granted by the Health Research Ethics Committee of the Faculty of Health Sciences of the institution where the research was conducted (NWU-00200-14-A1). The study was 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 of South Africa.

Testing Procedures

Two weeks either before or after soccer matches, players completed a test battery which consisted of a 40-m maximum speed test, followed by the execution of a Yo-Yo IR1 test. These tests were performed to determine the individual velocity and HR thresholds of each player for use during match analyses. GPS units together with Fix Polar Heart Rate Transmitter Belts (Polar Electro, Kempele, Finland) were used to monitor velocity and heart rates during five university-level soccer matches.

40-m maximum speed test. The 40-m maximum speed test was preceded by a standardised warm-up consisting of jogging and dynamic stretches followed by 10-minute bursts of running. The time for the 40-m maximum speed test was measured using photocells (Brower Timing Systems, South Draper, UT) placed at the start, 30 and 40 m on a grass soccer field. Players wore their soccer boots during execution of the speed test. When ready, players sprinted from a static position. Each participant had 2 trials separated by at least 3 minutes of rest, and the fastest time was recorded to the nearest 0.01 s. To determine the maximum velocity ($m.s^{-1}$) of each player, the 30-m split time was subtracted from the 40-m split time. Ten (representing 10 m) was then divided by this value (28).

The velocity thresholds suggested for soccer by Dwyer and Gabbett (18) were used for this study. The thresholds were determined as a percentage of each player's maximum velocity (as obtained from the 40-m maximum speed test). The general threshold speed guidelines of Dwyer and Gabbett (18) show that the moderate-intensity velocity zone (MIVZ) is between 34% and 61% of players' maximum velocity; the low-intensity velocity zone (LIVZ) was therefore set at <34% of maximum velocity and the high-intensity velocity zone (HIVZ) at >61% of the maximum velocity. For a movement to be recorded as an effort players had to maintain that velocity for at least 1 s.

Yo-Yo IR1. The Yo-Yo intermittent recovery test, level 1 (Yo-Yo IR1) was chosen as the preferred test for this study in view of the fact that it showed significant correlations ($r = 0.71$; $p < 0.05$) with the amount of high-intensity running during a soccer match (28). The Yo-Yo IR1 has also been widely applied in many team sports to evaluate the ability of players to repeatedly perform high-intensity exercise (5). A significant correlation between $\dot{V}O_{2max}$ and Yo-Yo IR1 results ($r = 0.70$, $p < 0.05$) provides evidence that the Yo-Yo IR1 is a valid exercise test for determining players' $\dot{V}O_{2max}$ values (5). All players were familiar with the Yo-Yo IR1 as they had performed it previously before the commencement of the study. The test was conducted on a flat, clearly marked 20 m stretch of a grass soccer field. Players wore their soccer boots during the test. Players were required to run back and forth on the 20-m track and pace themselves so that the arrival at the end of the 20-m stretch coincided with the signal emitted from a commercially available pre-recorded compact disc (CD) (Bangsbosport.com, Bangsbosport Aps, Espergaerde, Denmark). Players were required to cross the marked lines at either end of the 20-m stretch with one foot as the signal sounded from the CD. Players received a brief 10-s active recovery after each 40-m (2 x 20 m) shuttle during which they walked back and forth over a 5-m stretch. The test started at a speed of 10 $km.h^{-1}$ and was progressively increased until test termination. The test was terminated due to players voluntarily stopping or when a player could not make it to either end marks of the 20-m distance within the given signal time in two successive shuttles.

Players performed the Yo-Yo IR1 while wearing a portable gas analyser apparatus (Metamax 3B, Cortex, Leipzig, Germany) and a Fix Polar Heart Rate Transmitter Belt (Polar Electro, Kempele, Finland), which were used to sample expired air and record heart rate continuously. The rate of oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), minute ventilation ($\dot{V}_E$), respiratory exchange ratio (RER) and HR were recorded every 5 s. Vogler et al. (44) found the MetaMax 3B to be a reliable and valid portable gas analyser. The MetaMax 3B overestimated $\dot{V}O_2$, $\dot{V}CO_2$, and $\dot{V}_E$ by approximately 4%, 7%, and 4% respectively compared to the values of an automated Douglas bag system (44). The MetaMax3B also yielded excellent reproducibility with typical errors of 2–3% for $\dot{V}O_2$, $\dot{V}CO_2$ and $\dot{V}_E$ (44). The portable gas analyser was calibrated with standard gases before commencement of the test. The criteria for reaching $\dot{V}O_{2max}$ was set as follows: a respiratory exchange ratio-value higher than 1.15 at test termination; oxygen consumption ceased to rise and reached a plateau or began to fall even though the work rate continued to increase, or the maximal age-specific HR was reached (15, 30). The VT was determined applying the criteria of an increase in $\dot{V}_E/\dot{V}O_2$ with no increase in $\dot{V}_E/\dot{V}CO_2$ and departure from the linearity of $\dot{V}_E$ (13). The RCP was taken as the point which corresponded to an increase in both $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$ (13).

VT and RCP were visually detected by two independent experienced observers as Weston and Gabbett (46) showed that this method is reliable (r = 0.91–0.97, p <0.0001) for the determination of both VT and RCP. The different gas exchange phases were used to determine the heart rates that corresponded to the three exercise intensities (13): Heart rates that correspond to the exercise intensities below VT were classified as low-intensity heart rates; heart rates between VT and RCP as moderate-intensity heart rates; and heart rates above RCP as high-intensity heart rates.

Match analyses. The GPS data of the starting line-up were monitored for the duration of five matches. All matches were analysed with GPS units sampling at a frequency of 10 Hz (MinimaxX V4.0, Catapult Innovations, Victoria, Australia) with a minimum of 8 satellites used to determine the position of each unit. The units were kept under open sky and turned on 10-min before each match. The GPS units were fitted to the upper back of each player by means of a harness. Players were familiar with the GPS equipment due to the fact that they regularly trained with the units fitted to their backs. The GPS units collected information on distances, velocities and intensities of all movements executed during the different soccer matches. The recordings from the GPS unit were downloaded to a PC and analysed using the Logan Plus V4.7.1 software (Catapult Sports, Victoria, Australia). The GPS Doppler data was used during the analyses of the GPS-related variables.

Although some uncertainty exists with regard to the validity and reliability of GPS devices to monitor small directional changes at high speeds, research suggests that GPS devices sampling at higher frequencies are more sensitive to these changes (41). Several studies have tested the validity and reliability of the 10 Hz GPS units (27, 41, 43) and concluded that the inter-unit reliability of the 10 Hz devices was good (technical error of measurement = 1.64%) when peak speed was measured (27) and showed to be reliable for measuring instantaneous velocity (coefficient of variation = 1.9–6.0%) (41).

Statistical Analyses

Analyses were conducted using IBM SPSS Statistics v. 21.0.0.0. Firstly, the velocities and heart rates obtained from each player during the matches were categorized into the three intensity zones (low, moderate and high) according to the Yo-Yo IR1 test results and speed test. The times spent in the different zones were then expressed as a percentage of the total match time (excluding the time before the matches and half-time). Secondly, the descriptive statistics (averages, minimum, maximum and standard deviation values) for each variable were calculated. Thirdly to determine whether a correlation existed between the time spent (relative and absolute) in a velocity zone and the corresponding HR zone, Spearman's rank correlation rho was used. In addition to the Spearman's rank correlation, a partial correlation was also performed to adjust for players' $\dot{V}O_{2max}$ values and Yo-Yo IR1 performance.

Furthermore, to determine the 90% confidence interval (CI) from the correlation coefficient (*r*) a Fisher r to z transformation was calculated. The level of significance was set at $p < 0.01$. The strength of correlations was also described according to the following criteria: <0.1 (trivial), <0.3 (small), <0.5 (moderate), <0.7 (large), <0.9 (very large) and <1 (nearly perfect) (24).

RESULTS

The descriptive statistics of the Yo-Yo IR1 as well as the match variables are presented in Table 1.

TABLE 1: Minimum, maximum and average values for the Yo-Yo IR1 as well as the internal and external match load-related variables.

Variables	Average ± SD	Min	Max
Yo-Yo IR 1 HR_{max} (bpm)	194 ± 7	183	202
Yo-Yo IR 1 distance (m)	1618 ± 429	1080	2240
$\dot{V}O_{2max}$ (ml.kg.$^{-1}$min^{-1})	61.9 ± 3.7	53.0	68.0
VT HR (bpm)	164 ± 10	144	177
VT HR (%)	84.5 ± 4.5	73.1	88.9
RCP HR (bpm)	187 ± 6	179	196
RCP HR (%)	96.6 ± 1.4	94.3	98.4
Maximum testing velocity (m.s^{-1})	8.6 ± 0.3	8.0	9.0
MIVZ start (m.s^{-1})	2.9 ± 0.1	2.7	3.1
HIVZ start (m.s^{-1})	5.2 ± 0.2	4.9	5.5
Match distance covered (m)	9329 ± 1286	6249	11511
Relative match distance covered (m.min^{-1})	96.3 ± 11.7	63.3	117.5
Maximum match velocity (m.s^{-1})	7.8 ± 1.4	6.2	15.0
Match $HR_{average}$ (bpm)	158 ± 10	139	176
Match HR_{max} (bpm)	200 ± 11	180	220

Yo-Yo IR1 – Yo-Yo intermittent recovery test 1; HR_{max} – Maximum heart rate; $\dot{V}O_{2max}$ - Maximum oxygen uptake; VT – Ventilatory threshold; HR – heart rate; RCP – Respiratory compensation point; MIVZ – Moderate-intensity velocity zone; HIVZ – High-intensity velocity zone; $HR_{average}$ – Average heart rate

Table 2 presents the absolute and relative time spent in the different intensity zones according to the external (velocity) and internal (HR) match data. The results show a large ($r = 0.5$; $p \leq 0.01$) correlation between the time spent in the LIVZ (5017 ± 368 s) and the LI HR zone (2891 ± 1086 s), with the true correlation value that varies between moderate and large. Similarly, a moderate ($r = 0.3$; $p \leq 0.01$) to large ($r = 0.6$; $p \leq 0.01$) correlation was found between the relative (11.4 ± 3.7%) and absolute time (669 ± 223 s) spent in the MIVZ and the MI HR zone (41.0 ± 16.8% and 2253 ± 752 s). However, the true correlation value for the absolute time spent in the MI zone falls between the large to very large category, whereas the correlation for the relative time was small to moderate. There were no significant correlations ($p \leq 0.01$) between the HIVZ and the HI HR zone. Only small correlations were found between variables when adjusting for $\dot{V}O_{2max}$ and Yo-Yo IR1 performance.

TABLE 2: Correlations between the external and internal match load intensity zones (n = 44).

Variable	Velocity	HR	*r*	*z*	90% CI
LI zone (s)	5017 ± 368	2891 ± 1086*	0.5^{L}	4.910	0.3 to 0.6
LI zone (%)	87.2 ± 4.1	49.4 ± 20.9	0.1	1.455	-0.0 to 0.3
MI zone (s)	669 ± 223	2253 ± 752*	0.6^{L}	6.487	0.5 to 0.7
MI zone (%)	11.4 ± 3.7	41.0 ± 16.8*	0.3^{M}	2.681	0.1 to 0.4
HI zone (s)	80 ± 33	370 ± 503	0.1	0.998	-0.1 to 0.3
HI zone (%)	1.3 ± 0.6	5.1 ± 7.6	0.0	0.287	-0.1 to 0.2

LI – Low-intensity; MI – Moderate-intensity; HI – High-intensity; HR – Heart rate; *$p < 0.01$; $^{M/L}$ – Moderate/ large correlation between velocity and heart rate.

DISCUSSION

The present study compared the match analysis results of different methods aimed at determining the external and internal match loads of a cohort of university-level soccer players. This study is the first to use individualised thresholds to concurrently determine the internal and external loads of several competitive university-level soccer matches. The main finding of this study was that there were moderate to large correlations between the external and internal match loads at low and moderate intensities, but only small correlations were found at high intensities. Furthermore, when adjusting for Yo-Yo IR1 performance and $\dot{V}O_{2max}$, only small correlations were found between the external and internal match load-related variables. Therefore it can be assumed that the relationships between velocity and heart rate zones are dependent on the fitness levels of players.

Without the adjustment for fitness levels the results showed that a significant large (r = 0.5, $p \leq 0.01$) correlation occurred between the time spent in the LIVZ (5017 s) and the LI HR zone (2891 s), with the true correlation value varying between moderate and large. Similarly, there was a significant ($p \leq 0.01$) moderate (r = 0.3) to large (r = 0.6) correlation between the relative (11.4%) and absolute (669 s) time spent in the MIVZ compared to the MI HR zone (41.0% and 2253 s respectively). However, the true correlation value for the absolute time spent in the MI zone fell between the large to very large category whereas the correlation for the relative time varied between small and moderate. There were no significant correlations ($p \leq 0.01$) between the HIVZ and the HI HR zone. What is apparent from these results is that high correlations were visible while players were spending time in low- to moderate-intensity zones, but decreased as players moved into the higher-intensity zones. When players are engaged in sudden HI activities, the heart responds by increasing the stroke volume and not the stroke frequency (Frank-Starling stall) (8). Therefore, during soccer matches, the HR will probably not immediately respond to sudden velocity increases, which may explain the differences in correlation values between different intensity zones. Despite this, players spent more time (absolute and relative) in the HI HR zone than the HIVZ. According to Reilly (36), monitoring only external loads during match play may underestimate the real loads players experience during a match due to the fact that researchers do not account for the extra skills (e.g. dribbling, kicking etc.) that are executed during the match.

Subjects in this study covered an average distance of 1 618 m during the Yo-Yo IR1 which is lower than the distance reported by Randers et al. (35) (2950 m). However the $\dot{V}O_{2max}$ of our players were higher (61.9 $ml.kg.^{-1}min^{-1}$) than the 56.3–59.0 $ml.kg.^{-1}min^{-1}$ reported by others (1, 6, 34). Furthermore, the average HR_{max} during the Yo-Yo IR1 was higher (194 bpm) than the HR_{max} achieved during a maximal treadmill test by Abt and Lovell (1) (185 bpm). This supports the notion that there are differences in the muscle recruitment patterns, energy demands and type of movements performed between a field test and a continuous treadmill-running test. Similarly the HR thresholds as determined by the VT and RCP in this study revealed that the absolute (187 bpm) and relative (96.6%) HI HR values were higher than the values reported by Abt and Lovell (1) (172 bpm, 93.0%). However, the absolute (164 bpm) MI HR values were similar (160 bpm) to those recommended by Bangsbo (4) and the relative MI HR values slightly higher (84.5% *vs* 80.0%). A comparison between the velocity threshold values of this and previous studies revealed that the MIVZ threshold (2.9 $m.s^{-1}$) was similar to those of Randers et al. (35) (2.5 $m.s^{-1}$) and Dwyer and Gabbett (18) (2.1 $m.s^{-1}$). The HIVZ threshold value (5.2 $m.s^{-1}$) was also similar to the values of Burgess et al. (11) (5.0 $m.s^{-1}$), Carling (12) (5.3 $m.s^{-1}$) and Varley et al. (42) (5.5 $m.s^{-1}$).

During matches players in the current study covered an average distance of 9 329 m which is comparable to the average distance (9 425 m) reported by Barrett et al. (6) on university-level soccer players. However, the majority of studies reported average distances of between 10 063 m and 10 700 m (35, 42, 45). Furthermore, the professional players in the studies of Wehbe et al. (45) and Varley et al. (42) covered these distances at an average intensity of 109 $m.min^{-1}$ and 104 $m.min^{-1}$ respectively, which is more than the 96 $m.min^{-1}$ observed in this study. Moreover, the average HR achieved during matches in this study was 158 bpm whereas other studies reported heart rates of between 157 bpm and 170 bpm (3, 14, 20). Direct comparisons for the time spent in the different intensity zones between this and previous studies are difficult due to differences in movement categorisations between studies. Furthermore, the majority of studies do not report the absolute time spent in the different velocity zones but rather the absolute and relative distances covered in these zones. Nevertheless, the players in this study spent more time in the LIVZ (5 017 s) and less time in the MIVZ (669 s) than players in a study by Impellizzeri et al. (25) (3 423 s and 1 571 s respectively). Our players also spent less time in the HIVZ (80 s) than players in studies by Rampinini et al. (34) (128 s) and Bradley et al. (10) (150 s). However, it is important to note that these studies were performed on professional and not university-level soccer players. In this regard it has previously been shown that top-level soccer players perform more HI activities than their lower level counterparts (31). This finding could therefore explain the large differences for time spent in the HIVZ between this study and other studies.

With regard to the HR zones, Eniseler (20) used lactate reference values to categorise heart rates into low-, moderate- and high-intensity HR zones. Similar values were found for the total time spent in the MI HR zone (37%) for professional soccer players compared to the values of players in this study (41%) (20). However, in our study players spent more relative time in the LI HR zone (49%) and considerably less time in the HI HR zone (5%) than the players in the study of Eniseler (20) (14% and 50%). Although Impellizzeri et al. (25) used a threshold value of 95.0% of HR_{max}, which is similar to the HI HR zone (96.6% of HRmax) of this study, they reported a value of 226 s for the time spent in the HI HR zone which is lower that the value of this study (370 s). However, it is must be noted that the matches in the last-mentioned study were 30 min shorter than the matches in the current study. Therefore players in the current study had much more time to spend in the HI HR zone.

In summary, this is the first study to use individualised thresholds to concurrently determine the internal and external loads of several competitive university-level soccer matches.

Results revealed moderate to large correlations between the external and internal match loads at low and moderate intensities, but only small correlations at high-intensities. However, further analysis would suggest that these correlations are dependent on players' fitness levels. Furthermore, results revealed that university-level soccer players spent most of their time in the LIVZ and LI HR zones. However, the results of the present study must be interpreted with caution, since a small sample size was used. The results are therefore only applicable to university-level soccer matches. Thus, the accuracy of this method for determining the internal and external loads of soccer matches should be measured and tested on soccer players of different participation levels.

PRACTICAL APPLICATIONS

When analysing soccer matches it is suggested that researchers use individually determined thresholds to examine both the internal and external loads of soccer matches concurrently. When using GPS alone the energy expended during matches are underestimated due to extra skills (e.g. dribbling, kicking etc.) which this type of analysis does not detect. On the other hand, the use of only heart rates may lead to errors in describing the match loads of especially high-intensity movements due to the inability of the heart to immediately respond to sudden velocity increases. Therefore in order to obtain more accurate results with regard to the loads soccer players experience during match-play, sports practitioners and sports scientists need to apply methods that allow them to simultaneously analyse both the internal and external match loads.

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CHAPTER 6

6 SUMMARY, CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS

1. SUMMARY

Soccer is the most popular sport in the world and is played by both men and women. The popularity of soccer and the substantial financial rewards players and the coaching staff receive when achieving success have forced conditioning coaches and sport scientists to apply more reliable and accurate methods for analysing the demands of matches, thereby enabling them to construct effective training programs. However, to date no gold standards exist to measure the loads placed on soccer players during matches. Furthermore, very few studies make use of physiologically determined individualised thresholds to quantify these match loads. Although several studies have determined the external loads of soccer matches and some have determined the internal loads, hardly any studies have concurrently investigated the internal and external loads placed on players during competitive soccer matches. Therefore the predominant aim of this study was to use physiologically determined individualised thresholds to define both the external and internal match loads of university-level soccer players. In order to reach this aim the following objectives were posed:

- To determine the fatigue rates and patterns of a cohort of university-level soccer players during matches when using global positioning system (GPS) to quantify the high-intensity running performances in rolling 5-min periods.

- To determine the influence of Yo-Yo intermittent recovery test- (Yo-Yo IR1) determined training status of a cohort of university-level soccer players on fatigue patterns and rate during match-play.
- To determine the positional-internal match loads of a cohort of university-level soccer players by making use of heart rates and the Yo-Yo IR1-determined threshold values.
- To compare the match analysis results of different methods aimed at determining the external and internal match loads of a cohort of university-level soccer players.

Chapter one contained a brief introduction as well as a problem statement which underlies the research questions, objectives and hypotheses that form the foundation of this study. This thesis is submitted in article format, as approved by the Senate of the North-West University (Potchefstroom Campus); therefore includes a literature review (chapter two) and three research articles (chapters three, four and five respectively) which will be presented to internationally recognised peer-reviewed journals.

In Chapter two the literature from the past decade was cited firstly to describe the various soccer match analysis methods used in scientific literature as well as to present the results of research on each of the methods applied with a view to determine soccer match loads. Secondly, the author explored the limitations of the different methods and finally, paid attention to other methods that can also be applied to strengthen the accuracy and validity of soccer match analyses results.

Match analysis can fall into two broad categories, namely those methods used to determine the external loads (velocity, distance, accelerations etc.) and those used to determine the internal loads players experience during matches (heart rates, blood lactate, rate of perceived exertion (RPE)). From the 27 soccer match analysis studies identified that determine the external match loads, the majority of studies (18) used semi-automated tracking systems whereas studies using GPS and manual video tracking to analyse soccer matches accounted for five and four studies respectively. These methods found that the average total distance covered per match by players was 9–12 km. They also found that midfielders tend to cover greater distances than defenders and attackers. Furthermore, several studies suggested that temporary fatigue occurred after the most intense periods during a match and also during the last 15 minutes of a match.

Although the last-mentioned methods provide researchers with valuable information with regard to the external match loads of players, certain limitations need to be considered. For example, semi-automated systems are extremely expensive and users are confined to the area of installation. Also, even though manual video tracking is relatively inexpensive it is very time-consuming and the accuracy is dependent on the experience level of the researcher. GPS on the other hand has made it possible for researchers to analyse matches in real-time, but unfortunately FIFA laws do not allow players to wear GPS units while they are playing soccer matches which makes GPS monitoring of FIFA accredited soccer matches impossible.

Due to the fact that match analyses alone do not provide a true reflection of the demands of soccer match-play if the internal match loads of players are not determined, the monitoring of heart rates, RPE and the use of physiologically determined thresholds are also necessary. However, only one study has thus far used individualised, blood lactate-determined heart rate zones for each soccer player to show that players had spent 50% of the time in the highest intensity zone (> 4mM blood lactate concentration). Notwithstanding the fact that no researchers have applied other individualised methods to determine the internal match loads of soccer players, researchers used heart rates as well as graded maximal test results to determine the match loads of rugby players. This study found that rugby players spent the highest percentage of match time (44%–83%) in the high-intensity zone. However, the use of laboratory instead of field-based tests for determining the different HR intensity zones can be questioned in view of differences in the muscle recruitment patterns and energy demands between an intermittent sport and a laboratory test. The Yo-Yo IR1 meets all the requirements to possibly serve as a more soccer-specific test for determining the different HR intensity zones as well as training status of players for possible prediction of fatigue development during soccer matches.

From this literature review it became clear that there is a need to use individualised methods to simultaneously analyse both the internal and external match loads of players. It is with this background that the results of this study were presented in three research papers.

Chapter three contains the research article titled “The use of a global positioning system to determine variations in high-intensity running and fatigue in a cohort of university-level soccer players” by Sparks, M., Coetzee, B. and Gabbett, T.J. which will be presented for publication to the Journal of Science and Medicine in Sport. The aims of this study were to: (1) determine the fatigue rates and patterns of a cohort of university-level soccer players during matches when using GPS to quantify the high-intensity running performances in rolling 5-min periods and (2) determine the influence of Yo-Yo IR1-determined training status of a cohort of university-level soccer players on fatigue patterns and rate during match play.

Chapter four presents the research article titled "The use of heart rates and Yo-Yo intermittent recovery test-derived threshold values to determine the positional, internal match loads of university-level soccer players" by Sparks, M., Coetzee, B. and Gabbett, T.J. which has been submitted to the Journal of Sports Sciences. The aim of this study was to determine the positional-internal match loads of a cohort of university-level soccer players by making use of heart rates and the Yo-Yo IR1-determined threshold values.

Chapter five contains the research article titled "Internal and external match loads of university-level soccer players: a comparison between methods" by Sparks, M., Coetzee, B. and Gabbett, T.J. which will be submitted to the Journal of Strength and Conditioning research. The aim of this study was to compare different methods of determining the external and internal match loads of university-level soccer players.

2. CONCLUSIONS

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

Hypothesis 1: *GPS-determined high-intensity running performances in rolling 5-min periods will indicate that activity levels during a match have a significant effect on the fatigue patterns and rates of a cohort of university-level soccer players.*

The results from this study show that there is a decline in high-intensity running after the most intense 5-min period, which indicates temporary fatigue. Furthermore the study shows that activity level during the first half influences the total distance covered in the second half as well as the distance covered *via* high-intensity running. When comparing performances between the first and second half, the moderate-activity group were able to maintain the same distance and high-intensity running distance throughout the entire match. The low-activity group, however, showed a decline in distance covered during the first 5 min of the second half. Interestingly, the low-activity group showed an increase in distance covered during the final 10 min of the game as well as an increase in high-intensity running during the 80–85th min period. In contrast, the high-activity group showed a decline in distance covered during the first 15 min of the second half as well as a decrease in high-intensity running during the first 10 min of the second half. The high-activity group also showed a decrease in distances covered during the 70–75th min and 85–90th min periods.

To conclude, first half activity profiles had a significant impact on fatigue after the most intense 5-min period as well as on second-half performance. This suggests a degree of transient fatigue. Our study also supports the possibility that players pace themselves during matches with an end-spurt occurring towards the end of a match.

Hypothesis 1 is therefore *accepted.*

Hypothesis 2*: The Yo-Yo IR1-determined training status of a cohort of university-level soccer players will have a significant negative relationship with fatigue patterns and rates during match-play.*

In this study the Yo-Yo IR1 performance showed no significant correlation with any of the fatigue-related variables. However, it is worth noting that even though there was no significant correlation between Yo-Yo IR1 test performance and players' activity profiles, the Yo-Yo IR1 results were better for players in the high activity group.
To conclude, no relationships were found between Yo-Yo IR1 performance and any of the HIR running- and fatigue-related variables, but results suggest that Yo-Yo IR1 performance contributed to a better first-half performance.

Hypothesis 2 is therefore *rejected.*

Hypothesis 3: *The use of the heart rates and the Yo-Yo IR1-determined threshold values of a cohort of university-level soccer players will show significant positional differences in internal match loads.*

The positional analyses revealed that attackers spent significantly more time in the low-intensity heart rate zone than did defenders and midfielders. They also spent significantly less time in the high-intensity heart rate zone than the defenders. Although midfielders only spent statistically more relative time in the moderate-intensity heart rate zone attackers, midfielders and defenders spent practically significant more time in the moderate-intensity heart rate zone than did attackers.

To conclude, significant differences were observed for the internal match loads when different positional groups were compared.

Hypothesis 3 is therefore *accepted.*

Hypothesis 4: *No significant relationships between the external and internal match loads of a cohort of university-level soccer players.*

The results showed that a large, significant correlation existed between the time spent in the low-intensity velocity zone and the low-intensity heart rate zone, with the true correlation value that varied between moderate and large. Similarly, there was a significant, moderate to large correlation between the relative and absolute time spent in the moderate-intensity velocity zone compared to that of the moderate-intensity heart rate zone. The true correlation value for the absolute time spent in the moderate-intensity zone fell between the large to very large category whereas the correlation for the relative time between small to moderate. There were no significant correlations between the high-intensity velocity zone and the high-intensity heart rate zone. However, when adjusting for maximum oxygen uptake and Yo-Yo IR1 performance there were no significant correlations between any of the internal and external match load-related variables

To conclude, it is apparent that significantly high correlations existed between relative and absolute time spent in low to moderate velocity and heart rate intensity zones, but that these correlations decreased at higher intensity workloads. Furthermore, training status did not affect the size of correlations between the internal and external match load-related variables of players.

Hypothesis 4 is therefore *partially accepted*.

Our study is the first to use rolling 5-min periods to investigate the fatigue levels 15 minutes after the most intense period as well as during the second half of semi-elite soccer matches. It is also the first study to investigate the influence of training status and activity levels on these fatigue patterns. Although several studies have investigated the fatigue patterns of soccer players, they monitored pre-determined 5- or 15-min intervals. One study also investigated the fatigue patterns by using rolling 5-min intervals, but did not analyse the 15-min period after the most intense period. However, one study investigated the 10- and 15-min period after the most intense period, but did not explore the influence of activity levels on these recovery periods. Nonetheless, all of the last-mentioned studies did these investigations on professional soccer players.

With regard to the internal match loads of soccer players our study is the first to use a sport-specific maximum field-test to determine the intensity thresholds for each player. A number of studies have used heart rates to determine these loads but these studies either used generic guidelines based on the maximum heart rates of players or used the same intensity zones for all players. None of these guidelines were, however, physiologically determined.

Currently there is a great debate among researchers on which methods should be used to determine the match loads of soccer players. Several studies have investigated the external and internal match loads of soccer players respectively. However, this study used methods to determine the external and internal loads of competitive semi-elite soccer matches concurrently. Furthermore, both the external and internal load determining methods were individualised for each payer. It is also the first study to examine the relationship between the external and internal match loads of semi-elite soccer players.

Therefore this study contributed greatly to a better understanding of not only the internal and external match loads of soccer players, but also emphasized the importance of using physiologically determined individualised thresholds when analysing soccer matches. Furthermore, the study highlighted the importance of using both internal and external methods concurrently to describe the match loads of players.

3. LIMITATIONS AND RECOMMENDATION

Although this study provided valuable information with regard to the individualised external and internal match loads of university-level soccer players, several limitations should, however, be considered together with recommendations for future researchers who want to work on this area of research:

- The amount of high-intensity running activities was possibly underestimated as accelerations and decelerations were not considered during analysis of match-related data. We can therefore recommend that researchers in future consider the number of accelerations and decelerations that occur during match play when quantifying high-intensity running activities to determine fatigue rate and -patterns.
- Although signs of fatigue and possible pacing strategies were observed in this study, contextual factors such as the tactical role of players and the actual time the ball was in play may also influence the last-mentioned results. These factors should therefore be considered when performing studies on fatigue and pacing strategies in soccer.
- The results of the present study must be interpreted with caution as only a relatively small sample size of university-level soccer players were used in this study. The accuracy of the individualised, physiologically determined thresholds established in this study should therefore be verified in studies on soccer players of different participation levels.

APPENDICES

APPENDIX A GUIDELINES FOR AUTHORS

JOURNAL OF SCIENCE AND MEDICINE IN SPORT

Contributors are invited to submit their manuscripts in English to the Editor for critical peer review. The Journal of Science and Medicine in Sport considers for publication manuscripts in the categories of:

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- Sub-headings are generally not accepted. Incorporate into the text if required.
- Footnotes are not acceptable.
- Keep the use of tables, figures and graphs to a minimum.
- See notes on Tables, Figures, Formulae and Scientific Terminology at the end.

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- A structured abstract of less than 250 words (not included in 3000 word count) should be included with the following headings: Objectives, Design, Method, Results, and Conclusions

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v. Conclusion
vi. Practical Implications - 3 to 5 dot (bulleted) points summarising the practical findings derived from the study to the real-world setting of sport and exercise - that can be understood by a lay audience. Avoid overly scientific terms and abbreviations. Dot points should not include recommendations for further research.
vii. Acknowledgments - this section is compulsory. Grants, financial support and technical or other assistance are acknowledged at the end of the text before the references. All financial support for the project must be acknowledged. If there has been no financial assistance with the project, this must be clearly stated.
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the American Psychologist 30:682- 684, 1975, and to be sensitive to the semantic description of persons with chronic diseases and disabilities, as outlined in an editorial in Medicine & Science in Sports & Exercise_, 23(11), 1991. As a general rule, only standardized abbreviations and symbols should be used. If unfamiliar abbreviations are employed, they should be defined when they first appear in the text. Authors should follow Webster's Tenth Collegiate Dictionary for spelling, compounding, and division of words. Trademark names should be capitalized and the spelling verified. Chemical or generic names should precede the trade name or abbreviation of a drug the first time it is used in the text.''

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

MANUSCRIPT PREPARATION

1. Title Page

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

2. Blind Title Page

A second title page should be included that contains only the manuscript title. This will be used to send to the reviewers in our double blind process of review. Do not place identifying information in the Acknowledgement portion of the paper or anywhere else in the manuscript.

3. Abstract and Key Words

On a separate sheet of paper, the manuscript must have an abstract with a limit of 250 words followed by 3 – 6 key words not used in the title. The abstract should have sentences (no headings) related to the purpose of the study, brief methods, results, conclusions and practical applications.

4. Text

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

A. Introduction. This section is a careful development of the hypotheses of the study leading to the purpose of the investigation. In most cases use no subheadings in this section and try to limit it to 4 – 6 concisely written paragraphs.

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

C. Results. Present the results of your study in this section. Put the most important findings in Figure or Table format and less important findings in the text.Do not include data that is not part of the experimental design or that has been published before.

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

E. Practical Applications. In this section, tell the ‘‘coach’’ or practitioner how your data can be applied and used. It is the distinctive characteristic of the JSCR and supports the mission of ‘‘Bridging the Gap’’ for the NSCA between the laboratory and the field practitioner.

5. References

All references must be alphabetized by surname of first author and numbered. References are cited in the text by numbers [e.g., (4,9)]. All references listed must be cited in the manuscript and referred to by number therein. For original investigations, please limit the number of references to fewer than 45 or explain why more are necessary. The Editorial Office reserves the right to ask authors to reduce the number of references in the manuscript. Please check references carefully for accuracy. Changes to references at the proof stage, especially changes affecting the numerical order in which they appear, will result in author revision fees. End Note Users: The Journal of Strength & Conditioning Research reference style, ftp://support.isiresearchsoft.com/pub/pc/styles/endnote4/J%20Strength%20Condition%20Res.ens may be downloaded for use in the End Note application: ftp:// support.isiresearchsoft.com/pub/pc/styles/endnote4/J%20 Strength%20Condition%20Res.ens.

Below are several examples of references:

Journal Article

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

Book

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

Chapter in an edited book

Yahara, ML. The shoulder. In: Clinical Orthopedic Physical Therapy. J.K. Richardson and Z.A. Iglarsh, eds. Philadelphia: Saunders, 1994. pp. 159–199.

Software

Howard, A. Moments ½software_. University of Queensland, 1992.

Proceedings

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

Dissertation/Thesis

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

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.

7. Figures

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Tables must be double-spaced on separate sheets and include a brief title. Provide generous spacing within tables and use as few line rules as possible. When tables are necessary, the information should not duplicate data in the text. All figures and tables must include standard deviations or standard errors.

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TERMINOLOGY AND UNITS OF MEASUREMENT

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

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

The basic and derived units most commonly used in reporting research in this Journal include the following: mass—gram (g) or kilogram (kg); force—newton (N); distance—meter (m), kilometer (km); temperature—degree Celsius (_C); energy, heat, work—joule (J) or kilojoule (kJ); power—watt (W); torque—newton-meter (N_m); frequency— hertz (Hz); pressure—pascal (Pa); time—second (s), minute (min), hour (h); volume—liter (L), milliliter (mL); and amount of a particular substance—mole (mol), millimole (mmol).

Selected conversion factors:

_ 1 N = 0.102 kg (force);

_ 1 J = 1 N_m = 0.000239 kcal = 0.102 kg_m;

_ 1 kJ = 1000 N_m = 0.239 kcal = 102 kg_m;

_ 1 W = 1 J_s-1 = 6.118 kg_m_min-1.

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

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APPENDIX B INFORMED CONSENT

Consent

Title of the project: Internal and external match loads of university-level soccer players: a comparison between methods

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

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

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

(Signature of the subject)

Signed at ....on ……………………………………….

Witnesses

1. ....

2. ....

Signed at .... on ……………………………………….

APPENDIX C GENERAL INFORMATION & MEASUREMENT FORM

General information & measurement form

GENERAL INFORMATION

Please write clearly!

1. GEOGRAPHICAL INFORMATION

1.1 Surname: **Initials** **First Name**

1.2 Age:

Years:	Months:

1.3 Birth date:

Year:	Month:	Day:

1.4 Job description (cross out the one that is applicable):

Student	Part-time employment	*Full-time employment	*Major sponsorship

** Please specify if you marked any of these two options:*

1.5 Permanent residential address in South Africa:

____
____
____
____

1.6 Permanent postal address in South Africa:

____
____
____

1.7 Phone numbers:

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

1.8 Ethnic group

White	Coloured	Black	Indian

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

2. INFORMATION REGARDING TRAINING HABITS

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

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

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

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

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

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

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

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

2.5 How many hours per day do you normally train?

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

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

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

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

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

2.8 How do you think does your coaching compare with those of international rugby players?

Does not compare well at all	Does not compare well	In some aspects the same	Very well

2.9 Do you spend any time on psychological preparation for soccer and competitions?

Never	*Sometimes	*Often	*Always

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

____

____

____

____

3. MEDICAL INFORMATION

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

Head/Neck:

____

____

____

Shoulder/Clavicle:

____

____

____

Arm/Elbow/Wrist/Hand:

____

____

____

Back:

____

____

____

Hip/Pelvis:

____

____

____

Thigh/Knee:

____

____

Lower leg/Ankle/Foot:

____

____

____

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

____

____

____

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

____

____

____

4. COMPETITION DATA

4.1 At what level are you competing this year?

____

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

Club	Provincial	National	International

4.3 How many matches, approximately, have you played?

Club =	Provincial/National =

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

Achievement	Competition	Date

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

Defender	Midfielder	Attacker

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POTCHEFSTROOM CAMPUS

NAME AND SURNAME:

____

	TRIAL 1	TRIAL 2	AVERAGE
STATURE (cm)			
BODY MASS (kg)			

SPEED

	TRIAL 1	TRIAL 2	FASTEST
5 M (SEC)			
10 M (SEC)			
30 M (SEC)			
40 M (SEC)			

Yo-Yo test

Yo-Yo test	Heart rate:	Level:

MATCH – DATE AND TIME OF MATCH: ______________________	
TEST COMPONENT	**VALUES**
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 - END OF MATCH (H:MIN)	
BREAK 1 (H:MIN)	
TIME - END OF MATCH (H:MIN)	

APPENDIX D LANGUAGE EDITING

20 November 2014

I, **Ms Cecilia van der Walt,** hereby confirm that I took care of the **editing of the thesis of Ms M Sparks titled** *INTERNAL AND EXTERNAL MATCH LOADS OF UNIVERSITY-LEVEL SOCCER PLAYERS: A COMPARISON BETWEEN METHODS.*

C. van der Walt

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