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ORIGINAL ARTICLE

Impact of a soccer match on the cardiac autonomic control of referees

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Abstract The purpose of this study was to assess the effect of a soccer match on the cardiac autonomic control of heart rate (HR) in soccer referees. Sixteen Spanish regional and third division referees (11 males: 26 ± 7 years, 74.4 ± 4.1 kg, 178 ± 3 cm, Yo-Yo IR1 ~600–1,560 m; 5 females: 22 ± 3 years, 59.3 ± 4.8 kg, 158 ± 8 cm, Yo-Yo IR1 ~200–520 m) participated with 24-h HR recordings measured with a Polar RS800 during a rest and a match day. Autonomic control of HR was assessed from HR variability (HRV) analysis. Inclusion of a soccer match (92.5% spent at >75% maximum HR) reduced pre-match (12:00–17:00 hours; small to moderate), post-match (19:00–00:00 hours; moderate to almost perfect), and night-time (00:00–05:00 hours; small to moderate) HRV. Various moderate-to-large correlations were detected between resting HRV and the rest-to-match day difference in HRV. The rest-to-match day differences of low and high-frequency bands ratio (LF/HF) and HR in the post-match period were moderately correlated with time spent at different exercise intensities. Yo-Yo IR1 performance was highly correlated with jump capacity and peak lactate, but not with any HRV parameter. These results suggest that a greater resting HRV may allow referees to tolerate stresses during a match day with referees who spent more time at higher intensities during matches exhibiting a greater LF/HF increment in the post-match period. The relationship between match activities, $\dot{V}O_{2\,max}$ and HR recovery kinetics in referees and team sport athletes of different competitive levels remains to be clarified.

Keywords Autonomic nervous system · Psychological stress · Fatigue · Recovery · Monitoring · Team sports

Introduction

Soccer referees have been examined at length regarding match activities and fitness characteristics (Castagna and D'Ottavio 2001; Catterall et al. 1993; D'Ottavio and Castagna 2001; Tessitore et al. 2007; Weston et al. 2007). These studies have examined the distance and intensity of movements (Castagna and D'Ottavio 2001; D'Ottavio and Castagna 2001; Weston et al. 2007) and heart rate (HR) profile (Catterall et al. 1993; Tessitore et al. 2007; Weston et al. 2006) to assist in the referees' preparation. While these characteristics may assist soccer referees, other physiological responses such as cardiac autonomic control have also been reported to be important for training-induced adaptations (Buchheit et al. 2010; Kiviniemi et al. 2007, 2010). For example, Kiviniemi et al. (2007) reported that daily exercise guided by HR variability (HRV) significantly improved cardiorespiratory fitness ($\dot{V}O_{2peak}$) while pre-defined exercise training failed to alter $\dot{V}O_{2peak}$

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in a group of moderately trained men. More recently, Kiviniemi et al. (2010) confirmed the benefits of HRV monitoring in moderately trained women. Therefore, long-term HRV monitoring for soccer referees may provide an important tool for enhanced training and performance. However, a greater understanding of the daily HRV exhibited by referees, and in particular with respect to soccer matches, is necessary for the potential use of HRV as a monitoring tool, and more specifically at the sub-elite level (e.g. regional) which represents the greater number of referees worldwide. Furthermore, as sub-elite referees have less time for training than their elite counterparts, HRV monitoring could be an interesting approach for time economy in training individualisation.

HRV has been extensively utilised as a non-invasive tool for the assessment of cardiac autonomic nervous system modulation (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology 1996) in the trained state (Leicht et al. 2003a; Hautala et al. 2009), during the short-term (Kaikkonen et al. 2010) and long-term (Hautala et al. 2001) post-exercise recovery; and following psychological stressors (Hamer and Steptoe 2007). Given the high physical (Castagna et al. 2007; Mallo et al. 2009) and psychological (Boyko et al. 2007; Weston et al. 2006) demands of soccer refereeing, it is important to assess the impact of soccer matches on cardiac autonomic control (i.e. HRV). Of particular importance is the post-exercise recovery which has been assessed acutely with long-recordings (Seiler et al. 2007), and in the long-term via night-time HRV recordings following training (Pichot et al. 2000), and after maximal (Hautala et al. 2001) and supramaximal loads (Al Haddad et al. 2009). These studies concluded that those individuals with a greater cardiovascular fitness (i.e. $\dot{V}O_{2\,max}$) exhibited a faster HRV recovery after maximal (Hautala et al. 2001) and submaximal exercises (Seiler et al. 2007), but not after supramaximal exercise (Al Haddad et al. 2009). To our knowledge, no studies to date have examined the post-exercise HRV recovery after team sports matches. Moreover, since previous studies have reported a lower impairment of HRV in those fitter individuals (Hautala et al. 2001; Seiler et al. 2007) further examination of the relationship between specific fitness (e.g. performance during the Yo-Yo Intermittent Recovery test—level 1, Yo-Yo IR1) (Krustrup et al. 2003; Castagna et al. 2007) and HRV may clarify the daily autonomic disturbances for referees.

Although studied to a lesser extent, the anticipatory effect of a stressful event on the cardiac autonomic control of HR (Hynynen et al. 2009; Mateo et al. 2011; Pieper et al. 2007, 2010) could be also of considerable relevance for soccer referees. For instance, Hynynen et al. (2009) reported no significant HRV differences between a control and a parachute jump day but an elevated HR before the jump for novice compared to experienced jumpers. More recently, Mateo et al. (2011) found significant changes in HRV indices due to pre-competitive anxiety alterations before a bicycle motocross competition. Moreover, Pieper et al. (2007) demonstrated a significant effect of work-related worry on HR and HRV, independently of the stress-related event. Recently, Pieper et al. (2010) showed that this worry effect on HR activity is still visible after 2 h of the worrying episode. Therefore, it may be speculated that soccer referees also experience a significant stress during the hours before matches, and that this anticipatory response could influence referees' cardiac autonomic control of HR prior to the match.

Thus, the aim of the current study was to examine the impact of a soccer match, a significant physical and psychological stressor, on the cardiac autonomic control (HRV) of soccer referees. It was hypothesised that soccer referees would experience lower HRV before and after matches compared to a rest day. In addition, the relationship between referees' fitness (i.e. Yo-Yo IR1 performance), match load, and HRV was examined to clarify the role of fitness for referee's HRV responses.

Materials and methods

Participants

Sixteen (11 males, 5 females) sub-elite (regional and third division) soccer referees from the Spanish League volunteered for this study (Table 1). All participants had a minimum of 6 or 8 years of experience as referees (for regional and third division officials, respectively) at the time of the study and trained 0–2 days/week for up to 1 h per day. All participants were informed of all procedures and provided informed written consent for this study in accordance with approval of the local ethics committee.

Study design and procedures

This study was conducted near the end of the soccer season (i.e. March–May) when referees may demonstrate their highest level of physical fitness (Weston et al. 2011). During the study, all referees officiated regional or third division matches of 90 min duration and consisting of male players. All matches started at 17:00 or 17:30 hours with the number of match spectators being $\sim$500 with referees provided with a low degree of police protection that could negatively influence their psychological well-being.

Twenty-four hour HR (R–R intervals) recordings of a match day (i.e. with a soccer match) and a rest day (i.e. without physical activity) were obtained via a HR monitor

Table 1 Referees' characteristics

	All ($n = 16$)	Women ($n = 5$)	Men ($n = 11$)
Age (years)	25 ± 9	22 ± 3	26 ± 5
Height (cm)	172 ± 11	158 ± 9	179 ± 3
Mass (kg)	69.8 ± 8.7	59.3 ± 4.8	75.1 ± 3.8
Yo-Yo IR1 (m)	832 ± 400	408 ± 125	1,044 ± 304
HR_{max} during Yo-Yo IR1 (beats min^{-1})	192 ± 9	192 ± 5	192 ± 10
HR_{max} during match (beats min^{-1})	195 ± 9	201 ± 8	194 ± 10
LA_{peak} (mmol $L^{-1)}$	9.7 ± 2.9	8.2 ± 1.9	10.5 ± 3.1
CMJ (cm)	31.9 ± 6.9	24.2 ± 2.4	36.1 ± 4.4

Values are mean values ± SD

Yo-Yo IR1 Yo-Yo intermittent recovery test level 1, LA_{peak} blood lactate measured immediately after the Yo-Yo IR1, *CMJ* maximum countermovement jump

(RS800, Polar Electro Oy, Finland) for each participant within a 7-day period in a randomised order. The validity of the RS800 HR monitor has recently reported to be similar to electrocardiographic recordings (ICC ≥ 0.8) (Wallén et al. 2011). Moreover, the RS800 monitor has previously demonstrated to be a practical tool with sufficient memory capacity for 24 h R–R recordings in a sport setting (Boullosa et al. 2010). All participants were advised not to perform any vigorous physical activity 48 h before the rest day. Each recording was separated by at least 48 h with all 24-h R–R recordings starting and finishing at 12:00 hours with soccer matches performed between 17:00 and 19:00 hours. Participants were advised to go to bed before 00:00 hours on both match and rest days. For the female referees, menstrual stage for 24-h recordings was not controlled as HRV was reported to be similar during the major hormonal stages of the menstrual cycle (Leicht et al. 2003b). Daily living activities were not recorded as it was expected that long-term HRV indexes remained relatively stable at various activity levels (Hautala et al. 2010).

The 24-h HR recordings were manually filtered (Polar Pro Trainer, v. 5.35.161, POLAR, Electro Oy, Finland) to exclude artifacts and exported for HRV analysis using custom designed software (Kubios HRV v2.0, University of Kuopio, Finland). Data were detrended and smoothed ($\lambda = 500$) with recordings analysed for time-domain and frequency-domain (i.e. Fast Fourier Transform, Welch's Periodogram with a 256 s window and 50% overlap) HRV measures. The HRV parameters examined were: the mean R–R interval; mean HR; the standard deviation of all normal R–R intervals (SDNN); root mean square of successive differences between normal sinus R–R intervals (RMSSD); the percentage of adjacent normal R–R intervals different by greater than 50 ms (pNN50%); low-frequency power (LF) (0.04–0.15 Hz); high-frequency power (HF) (0.15–0.4 Hz); and the ratio between the low- and high-frequency bands of the power spectral analysis (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology 1996). These parameters were determined for the pre-match (i.e. 12:00–17:00 hours), post-match (i.e. 19:00–00:00 hours) and night-time (i.e. 00:00–05:00 hours) periods of each day. These periods were selected to account for the soccer match (i.e. 17:00–19:00 hours) and influence of circadian rhythms on HRV (Armstrong et al. 2011). The rest-to-match day difference (%) for each period was also calculated as follows: (rest day − match day)/rest day × 100. For the evaluation of cardiovascular stress during matches, a HR profile based on the proportion of match time that referees spent at various exercise intensity categories based on the maximum HR (HR_{max}) exhibited during the Yo-Yo-IR 1 test (i.e. <65% HR_{max}; 65–75% HR_{max}; 76–85% HR_{max}; 86–95% HR_{max}; and >95% HR_{max}) was documented for each referee (Helsen and Bultynck 2004).

On a separate day with a minimum of 72 h after a match day or 48 h before a rest day, all participants were evaluated for their fitness level during a field testing session. This session was performed as part of the referee's normal seasonal training and was conducted outdoors on a soccer field of natural grass with participants donning their official match clothes and shoes. Heart rate was monitored during this field session with a portable heart rate monitor (RS800, Polar Electro OY, Kempele, Finland). Firstly, referees performed a warm-up of 10 min at an intensity of 60% of their age-predicted HR_{max} (Tanaka et al. 2001) followed by two countermovement jumps (CMJ) on a contact mat (Ergojump, Bosco System, Italy) interspersed with 15 s of rest. The best CMJ was selected for further analysis. Subsequently, referees performed the Yo-Yo IR1 (Krustrup et al. 2003) with participants encouraged to continue until volitional exhaustion as confirmed by a rating of perceived exertion (RPE) of >19 on the Borg 6–20 scale. Immediately following the Yo-Yo IR1 performance, a blood lactate sample was obtained from the fingertip and analysed with a portable device (Lactate Scout, Senslab, Germany) for the determination of maximal lactate (LA_{peak}). This device has recently been reported to exhibit good validity (correlation = 0.837) and reliability [coefficient of variation (CV%) = 8.8–10.2%] compared to laboratory analysers (Tanner et al. 2010).

Statistical analysis

Statistical analysis was performed with a statistical package (SPSS, v16.0.2, Chicago, ILL) with descriptives shown as mean ± SD. A Kolmogorov–Smirnov with Lilliefors Significance Correction was performed to verify the normal distribution of variables. Differences between parameters at different times (pre-match, post-match, and night-time) and days (rest, match) were examined using analysis of variance (ANOVA) for repeated measurements (time × day) and pairwise comparisons with Bonferroni correction. Given the low number of females, gender was not considered for analysis. Significant relationships between parameters were identified using Pearson moment product correlation coefficient (r). Bland–Altman plots were used to assess the association between rest-to-match day differences and the average of rest and match values (MedCalc, v11.6.1, Mariakerke, Belgium). The magnitude of the changes between days was assessed using effect size (ES) with threshold values of 0.2 (small), 0.6 (moderate), 1.2 (large), and 2.0 (very large) considered. Eta-squared (η^2) was calculated for each ANOVA as a measure of effect size. Threshold values for small, moderate, large and very large effects were assumed to be 0.01, 0.09, 0.25, and 0.50, respectively. Confidence intervals (90%) for the true mean change or between days differences were also estimated (Hopkins et al. 2009). Magnitude-based inferences about the true change in HR and HRV indices were made with reference to a small worthwhile change calculated as: 0.2 multiplied by the between-subject standard deviation expressed as CV%. Quantitative chances of substantial positive, trivial or negative changes were assessed qualitatively as follows: <0.5%, almost certainly; 0.5–5%, very unlikely; 5–25%, unlikely; 25–75%, possibly; 75–95%, likely; 95–99%, very likely; >99%, almost certainly. If the chance of having positive or negative changes were both >5%, the true difference was deemed unclear. Confidence intervals (90%) for coefficients of correlation were also estimated. The following criteria were adopted for interpreting the magnitude of correlations between parameters: <0.1, trivial; 0.1–0.3, small; 0.3–0.5, moderate; 0.5–0.7, large; 0.7–0.9, very large; 0.9–1.0, almost perfect. If the 90% confidence intervals overlapped the thresholds for substantially positive or negative values, the magnitude was considered unclear. Inferences about correlations were made with respect to a smallest worthwhile correlation of 0.1. A p value of <0.05 was set as the level of significance.

Results

For the pre-match recordings, mean HR and LF/HF were significantly greater and mean RR, RMSSD, pNN50, and HF were significantly lower on the match day compared to the rest day (Table 2). For the post-match recordings, very large significant differences in mean HR, RR and SDNN were found while RMSSD, pNN50 and LF exhibited large significant differences, and HF and LF/HF moderate significant differences (Table 2). Regarding the night-time recordings, moderate significant differences were observed for mean RR, SDNN, RMSSD, pNN50 and HF (Table 2). Interestingly, the rest-to-match day difference in HRV was similar for pre-match and night-time recordings, but greater for the post-match recordings (Table 2). Effect sizes estimated for ANOVA as eta-squared values (η^2) are presented in Table 3. For greater comparison in the future, gender-based HRV values are shown in Table 4.

During the soccer matches, referees exhibited a unique HR profile with the majority of match time (~92.5%) spent at an intensity >75% HR_{max} (Fig. 1). Females spent a greater amount of the match at higher intensities (>86% HR_{max}) compared to males. The HR_{max} recorded during the match was similar to that recorded during the Yo-Yo IR1 ($p = 0.156$, Table 1).

Significant correlations were identified for the rest-to-match day difference in HR and HRV parameters with their corresponding values during the rest day (Table 5). As expected, we also correlated pre-post changes with the average of the pre- and post- values (i.e. Bland–Altman plot) to confirm the association between variables (see examples in Figs. 2, 3). In addition, there were significant correlations among the time spent at various exercise intensity categories during matches and the rest-to-match differences in HR (>95% HRmax; $r = -0.687$; $p = 0.007$) and LF/HF in the 5 h immediately after matches (Fig. 4). Moreover, the time spent at 65–75 and 86–95% HR_{max} were significantly correlated to each other ($r = -0.876$; $p = 0.000$).

No correlations were detected between any HRV parameter and any field performance parameter considering the whole sample or males and females separately. Interestingly, CMJ performance and LA_{peak} were significantly and highly correlated to Yo-Yo IR1 performance for all referees ($r = 0.916$, $p = 0.000$; and $r = 0.761$, $p = 0.002$, respectively) and for males ($r = 0.809$, $p = 0.008$; and $r = 0.967$, $p = 0.000$, respectively.

Discussion

The most significant finding of the current study was that referees exhibited significantly lower HRV prior to and following a soccer match compared with a rest day. The rest-to-match day differences in pre-, post-match, and night-time HRV were significantly related to the rest day HRV with those referees exhibiting greater rest day HRV

Table 2 Heart rate variability measures prior to (pre-match), following (post-match) and at night-time of a rest and a match day in the whole example

Time	Rest day	Match day	Magnitude of changes between days		
			%Δ; ±90% CL	ES	Qualitative inference
Mean HR (bpm)					
Pre-	74.5 ± 8.0	84.8 ± 10.3[a]	17.3; ±11.0	1.14	Very likely
Post-	70.1 ± 6.4	94.7 ± 5.1[a,b]	36.1; ±6.1[d]	4.28	Almost certainly
Night	63.6 ± 11.5	69.5 ± 8.0[b]	17.3; ±17.0	0.60	Likely
Mean HR (%HR_{max})					
Pre-	37.4 ± 5.2	42.3 ± 5.1[a]	17.2; ±13.0	0.95	Very likely
Post-	34.9 ± 3.2	47.4 ± 1.9[a,b]	37.1; ±5.1[d]	4.70	Almost certainly
Night	31.8 ± 5.9	34.7 ± 3.9[b]	17.5; ±17.0	0.56	Likely
Mean RR (ms)					
Pre-	848 ± 83	743 ± 95[a]	−14.0; ±7.7	1.20	Very likely
Post-	888 ± 89	656 ± 35[a,b]	−26.0; ±5.2[d]	3.43	Almost certainly
Night	996 ± 144[b]	895 ± 105[a,b]	−14.2; ±9.7	0.81	Very likely
SDNN (ms)					
Pre-	56.8 ± 12.6	49.6 ± 10.7	−19.9; ±18.0	0.62	Likely
Post-	59.5 ± 10.8	37.4 ± 9.0[a,b]	−37.6; ±8.4[d]	2.22	Almost certainly
Night	59.9 ± 16.2	49.5 ± 10.9[a]	−20.1; ±13.7	0.75	Very likely
RMSSD (ms)					
Pre-	50.1 ± 19.5	38.6 ± 14.1[a]	−28.9; ±18.0	0.68	Very likely
Post-	53.8 ± 20.0	25.7 ± 9.8[a,b]	−50.9; ±11.0[d]	1.78	Almost certainly
Night	61.6 ± 23.12	45.9 ± 18.7[a]	−28.8; ±14.0	0.75	Very likely
pNN50 (%)					
Pre-	23.0 ± 13.0	13.6 ± 8.1[a]	−62.1; ±31.0	0.87	Very likely
Post-	27.1 ± 14.8	6.0 ± 4.6[a,b]	−78.7; ±25.0[d]	1.93	Almost certainly
Night	34.5 ± 18.3[b]	21.2 ± 16.9[a]	−53.0; ±27.0	0.76	Very likely
LF (ms^2)					
Pre-	2,083 ± 808	1,796 ± 726[b]	−27.3; ±41.0	0.37	Unclear
Post-	2,161 ± 685	1,163 ± 623[a]	−47.1; ±14.0[d]	1.52	Almost certainly
Night	1,943 ± 1,394	1,415 ± 651	−29.9; ±29.8	0.49	Likely
HF (ms^2)					
Pre-	945 ± 666	541 ± 333[a]	−40.0; ±27.0	0.77	Likely
Post-	993 ± 793	298 ± 241[a,b]	−67.2; ±34.0[d]	1.18	Very likely
Night	1,381 ± 914	835 ± 758[a]	−45.3; ±28.0	0.65	Very likely
LF/HF					
Pre-	3.0 ± 1.6	3.9 ± 1.7[a]	43.3; ±22.0[c]	0.55	Very likely
Post-	3.3 ± 1.9	5.1 ± 2.1[a]	74.5; ±33.0	0.90	Almost certainly
Night	2.2 ± 1.9[c]	2.6 ± 1.7[b]	45.0; ±99.9	0.22	Likely

Values are mean ± SD for mean heart rate (HR) in beats per minute (bpm), mean HR expressed as percentage of maximal heart rate (%HR_{max}), mean R–R interval (RR), root mean square of successive differences between normal sinus R–R intervals (RMSSD), standard deviation of all R–R intervals (SDNN), percentage of adjacent normal R–R intervals differing by more than 50 ms (pNN50), low-frequency power (LF), high-frequency power (HF) and low-frequency/high-frequency ratio (LF/HF). Magnitudes of difference between days are expressed as mean percentage change (%Δ) and 90% confidence limits (±90% CL)

ES effect size

[a] Different from rest day ($p < 0.05$)

[b] Different from both other time conditions within the same day ($p < 0.05$)

[c] Different versus “post-” ($p < 0.05$)

[d] Different versus “pre-” and night ($p < 0.05$)

Table 3 Effect sizes estimated for ANOVA as eta-squared values (η^2)

Main effect [p value (η^2)]		
Day	Time	Day × time
Mean HR (bpm)		
<0.001 (0.26) M > R	<0.001 (0.29) pre-, post- > night	<0.001 (0.11) post- > pre- > night
Mean HR (%HR_{max})		
<0.001 (0.25) M > R	<0.001 (0.28) pre-, post- > night	<0.001 (0.12) post- > pre- > night
Mean RR (ms)		
<0.001 (0.26) R > M	<0.001 (0.32) night > pre-, post-	0.003 (0.06) night > pre- > post-
SDNN (ms)		
<0.001 (0.36) R > M	0.054 (0.06) pre-, night > post-	0.001 (0.12) post- < pre-, night
RMSSD (ms)		
<0.001 (0.35) R > M	0.002 (0.13) night > post-	0.002 (0.07) pre-, night > post-
pNN50 (%)		
<0.001 (0.33) R > M	0.003 (0.14) night > post-	0.005 (0.05) pre-, night > post-
LF (ms^2)		
0.001 (0.21) R > M	0.212 (0.04) pre- > post-	0.079 (0.06) pre- > post-, night
HF (ms^2)		
0.001 (0.28) R > M	0.018 (0.12) night > post-	0.137 (0.02) pre-, night > post-
LF/HF		
0.001 (0.16) M > R	<0.001 (0.29) pre-, post- > night	0.026 (0.05) pre-, post- > night

RR mean R–R interval, *RMSSD* root mean square of successive differences between normal sinus R–R intervals, *SDNN* standard deviation of all R–R intervals, *pNN50* percentage of adjacent normal R–R intervals differing by more than 50 ms, *LF* low-frequency power, *HF* high-frequency power, *LF/HF* low-frequency/high-frequency ratio, *R* rest day, *M* match day, *Pre-* pre-match condition, *Post-* post-match condition, *Night* night time

more likely to exhibit a greater reduction in HRV prior to and following a soccer match. These results confirm that soccer matches significantly alter referees' daily autonomic control of HR most likely as a result of high psychological and physical stresses.

A novel finding of our study was that the autonomic control of HR for referees was significantly reduced in the hours prior to a match (i.e. lower pre-exercise HRV), as reflected by moderate changes for estimates of overall (i.e. SDNN) and short-term components of HRV (i.e. RMSSD, pNN50 and HF). Recent studies have suggested that emotional or psychological stresses associated with a working task could alter both HR and/or HRV (Pieper et al. 2007), for up to 2 h following a worrying task (Pieper et al. 2010), and independent of other factors (e.g. caffeine consumption or physical activity). Subsequently, the ensuing concern or mental preparation for the soccer match may have led to a heightened sympathetic response and/or attenuated parasympathetic modulation resulting in lower HRV for referees. In this regard, it should be noted that this autonomic response has been demonstrated to be independent of other factors such as physical activity or other daily activities like eating (Pieper et al. 2007, 2010). Consequently, mental preparedness may result in significant changes in sympatho-vagal balance for referees in the hours prior to a match that may impact on performance and/or cardiovascular function. Therefore, further studies are needed for the assessment of these stress-related responses with regard to subsequent refereeing performance. In addition, it may be interesting to find new strategies that could help referees in reducing this psychological stress in the hours before a match.

Of further interest was that referees with a greater HRV and a lower HR during the rest day experienced a greater rest-to-match day difference (Table 5). This may indicate that referees with a higher basal HRV demonstrate a greater autonomic response to stressors in accordance with the "autonomic resource hypothesis" (Hynynen et al. 2008). Hynynen et al. (2008) reported an attenuated autonomic response in both orthostatic and cognitive tasks in overtrained athletes when compared to a control group. These authors proposed that overtraining resulted in a reduction of HRV that limited the ability of the autonomic nervous system to respond to stress (Hynynen et al. 2008). Similarly, a limited HRV response has been reported for patients with coronary artery disease when compared to a group of healthy people exhibiting the same basal HRV values (Huikuri et al. 1994). The current findings suggest that a greater basal HRV may allow further usage of autonomic resources for soccer referees' responses to stress. In other words, the higher the HRV at rest, the greater the responsiveness of the autonomic nervous system. A similar response has been recently observed in young adults who exhibited a greater awake HRV and greater change in HRV from sleep to morning when compared to older middle-aged adults (Armstrong et al. 2011). These outcomes may provide further support for the need of enhanced HRV for athletes and referees to endure

Table 4 Heart rate variability measures prior to (pre-match), following (post-match) and at night-time of a rest and a match day in men and women separately

Women (n = 5)			Men (n = 11)		
Time	Rest day	Match day	Time	Rest day	Match day
Mean HR (bpm)					
Pre-	79 ± 3	95 ± 4	Pre-	73 ± 8	80 ± 9
Post-	66 ± 8	95 ± 4	Post-	72 ± 6	95 ± 6
Night	59 ± 4	69 ± 9	Night	66 ± 14	70 ± 8
Mean HR (%HRmax)					
Pre-	39 ± 2	47 ± 2	Pre-	37 ± 9	40 ± 4
Post-	33 ± 5	48 ± 3	Post-	34 ± 2	47 ± 1
Night	30 ± 2	34 ± 4	Night	33 ± 7	35 ± 4
Mean RR (ms)					
Pre-	794 ± 17	656 ± 24	Pre-	862 ± 88	783 ± 88
Post-	941 ± 115	655 ± 33	Post-	869 ± 74	656 ± 37
Night	1,034 ± 64	905 ± 115	Night	982 ± 177	897 ± 108
SDNN (ms)					
Pre-	59 ± 9	46 ± 3	Pre-	56 ± 14	51 ± 13
Post-	64 ± 8	40 ± 8	Post-	57 ± 11	36 ± 10
Night	66 ± 7	52 ± 14	Night	55 ± 18	49 ± 10
RMSSD (ms)					
Pre-	56 ± 21	33 ± 8	Pre-	48 ± 20	39 ± 15
Post-	71 ± 21	31 ± 9	Post-	47 ± 16	23 ± 10
Night	80 ± 14	56 ± 10	Night	52 ± 23	42 ± 14
pNN50 (%)					
Pre-	27 ± 12	11 ± 5	Pre-	22 ± 14	15 ± 9
Post-	41 ± 13	9 ± 5	Post-	22 ± 12	4 ± 3
Night	51 ± 11	33 ± 25	Night	27 ± 17	16 ± 9
LF (ms^2)					
Pre-	1,947 ± 400	1,536 ± 155	Pre-	2,120 ± 894	1,914 ± 855
Post-	1,853 ± 150	1,170 ± 482	Post-	2,273 ± 774	1,159 ± 699
Night	1,606 ± 392	1,085 ± 378	Night	2,096 ± 1,664	1,582 ± 743
HF (ms^2)					
Pre-	1,413 ± 959	504 ± 224	Pre-	817 ± 556	557 ± 381
Post-	1,723 ± 1,150	452 ± 261	Post-	727 ± 437	228 ± 206
Night	2,256 ± 902	1,359 ± 1,129	Night	983 ± 617	608 ± 395
LF/HF					
Pre-	1.8 ± 0.8	3.5 ± 1.3	Pre-	3.4 ± 1.6	4.1 ± 1.9
Post-	1.4 ± 0.6	3.3 ± 1.9	Post-	3.9 ± 1.8	5.9 ± 1.7
Night	0.9 ± 0.5	1.4 ± 1.0	Night	2.7 ± 2.1	3.2 ± 1.7

Values are mean ± SD

RR mean R–R interval, *RMSSD* root mean square of successive differences between normal sinus R–R intervals, *SDNN* standard deviation of all R–R intervals, *pNN50* percentage of adjacent normal R–R intervals differing by more than 50 ms, *LF* low-frequency power, *HF* high-frequency power, *LF/HF* low-frequency/high-frequency ratio

significant sympatho-vagal changes prior to and following match performances.

Training-induced HRV changes have been previously reported and associated with a greater $\dot{V}O_{2\,max}$ (Hautala et al. 2009). Subsequently, enhanced $\dot{V}O_{2\,max}$ may not only enhance match performance (Castagna and D'Ottavio 2001) but may also prepare referees for the significant stresses experienced prior to and following matches. In this regard, Hautala et al. (2001) reported a faster long-term HRV recovery in participants with a higher $\dot{V}O_{2\,max}$ while Al Haddad et al. (2009) reported significant correlations between LA_{peak} after a supramaximal test and some night-time parasympathetic indices. In the current study, we did not find any correlation between Yo-Yo IR1 performance and rest-to-match day differences or post-match HRV. Collectively, the current and previous results indicate that the fitness level of participants may mediate both stress tolerance and short- and long-term HRV recovery capacity after aerobic or supramaximal exercises but not short-term (≤10 h) HRV recovery after aerobic–anaerobic exercises as experienced during a soccer match. In the current study, referee's fitness was based upon Yo-Yo IR1 performance with actual $\dot{V}O_{2\,max}$ values needed for future studies to examine the impact of $\dot{V}O_{2\,max}$ on pre- and post-exercise HRV kinetics. This consideration is important as Yo-Yo IR1 performance was more dependent upon anaerobic metabolism as confirmed by its correlations with La_{peak} and CMJ in the current study.

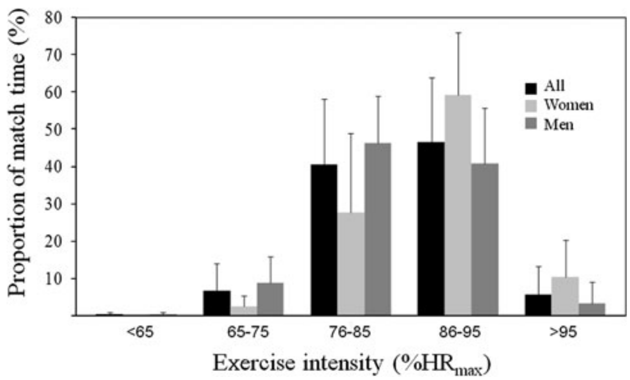

Fig. 1 Mean (SD) proportion of match time experienced by soccer referees (males, females and the whole group) within each exercise intensity category

Like the pre-match HRV measures, post-match HRV was also substantially lower following a soccer match compared to a rest day, as reflected in large-to-moderate changes in RMSSD, pNN50, LF, HF and LF/HF. The imbalanced post-match HRV may reflect both the physical as well as the psychological stresses experienced by referees. This reduced HRV was evident at 5–10 h following the match with a significantly greater impairment of HRV in the post-match period when compared to the similar night-time and pre-match rest-to-match day differences. In this regard, the correlations detected between the post-match LF/HF rest-to-match day difference and time spent at different $\%HR_{max}$ during matches (see Fig. 4), may indicate that the match load mediates the post-match sympatho-vagal imbalance. That is, the greater the time spent at higher %HRmax, and conversely the lower the time spent at lower %HRmax during the match, the greater the post-match LF/HF rest-to-match day difference. It should be pointed out that we do not know if an elevated HR during matches is a consequence of physical, psychological or a combination of these factors. However, it may be speculated that physical factors may be primary given the suggested relationship between an elevated HR and the

Table 5 Correlations between HR and HRV parameters and their respective rest-to-match day differences

Δ%	Rest day values								
	Pre-match			Post-match			Night-time		
	Correlation (90% CI)	*p* value	Qualitative inference	Correlation (90% CI)	*p* value	Qualitative inference	Correlation (90% CI)	*p* value	Qualitative inference
Mean HR	−0.36 (−0.70, 0.12)	0.253	Unclear	−0.82[a] (−0.93, −0.59)	<0.001	Almost certainly	−0.68[b] (−0.86, −0.35)	0.004	Almost certainly
Mean HR ($\%HR_{max}$)	−0.31 (−0.67, 0.17)	0.297	Unclear	−0.91[a] (−0.97, −0.79)	<0.001	Almost certainly	−0.80[a] (−0.92, −0.35)	0.001	Almost certainly
Mean RR	0.31 (−0.17, 0.67)	0.281	Unclear	0.83[a] (0.61, 0.94)	<0.001	Almost certainly	0.66[b] (0.32, 0.85)	0.006	Very likely
SDNN	0.79[a] (0.52, 0.92)	0.001	Almost certainly	0.26 (−0.20, 0.63)	0.344	Unclear	0.66[b] (0.33, 0.85)	0.005	Very likely
RMSSD	0.64[b] (0.26, 0.85)	0.014	Very likely	0.44 (−0.01, 0.74)	0.104	Likely	0.27 (−0.18, 0.62)	0.316	Unclear
pNN50	0.45 (−0.01, 0.75)	0.106	Likely	0.05 (−0.40, 0.48)	0.866	Unclear	0.23 (−0.22, 0.60)	0.393	Unclear
LF	0.70[a] (0.35, 0.88)	0.021	Very likely	0.06 (−0.40, 0.49)	0.840	Unclear	0.63[b] (0.28, 0.83)	0.009	Very likely
HF	0.67[b] (0.30, 0.86)	0.009	Very likely	0.37 (−0.09, 0.70)	0.173	Likely	0.40 (−0.03, 0.71)	0.13	Likely
LF/HF	−0.63[b] (−0.84, −0.23)	0.017	Very likely	−0.61[b] (−0.83, −0.24)	0.015	Very likely	−0.58[b] (−0.81, −0.21)	0.018	Very likely

RR mean R–R interval, *RMSSD* root mean square of successive differences between normal sinus R–R intervals, *SDNN* standard deviation of all R–R intervals, *pNN50* percentage of adjacent normal R–R intervals differing by more than 50 ms, *LF* low-frequency power, *HF* high-frequency power, *LF/HF* low-frequency/high-frequency ratio

[a] Very large correlation

[b] Large correlation

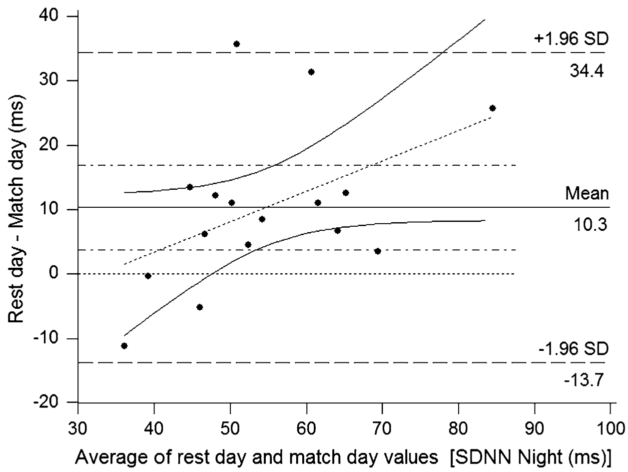

Fig. 2 Relationships between absolute rest-to-match differences and the average of rest and match day values in SDNN during the night time ($r = 0.47$; $p = 0.063$)

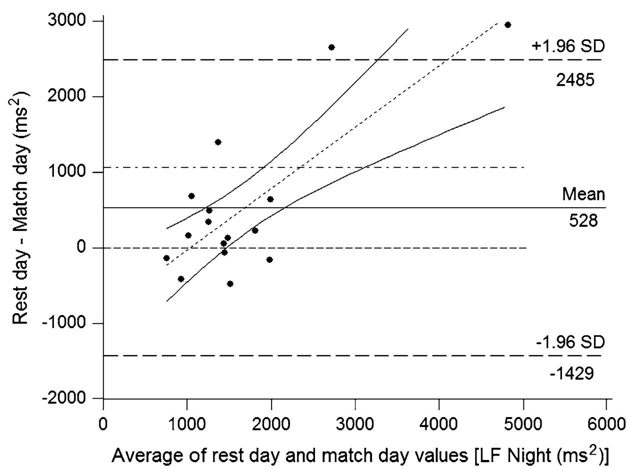

Fig. 3 Relationships between absolute rest-to-match differences and the average of rest and match day values in LF during the night time ($r = 0.79$; $p = 0.001$)

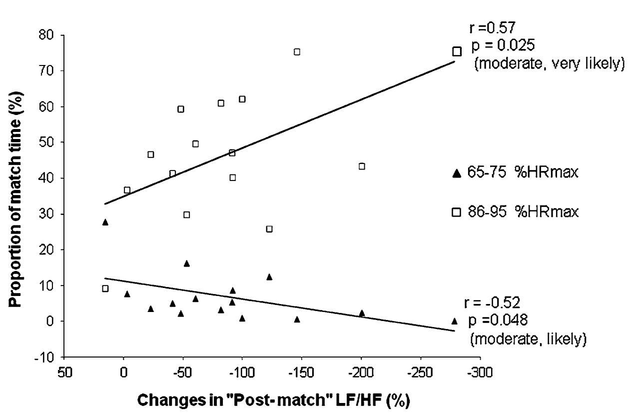

Fig. 4 Regression analysis among time spent at various exercise intensities during matches and the rest-to-match day difference in LF/HF (%)

number of high-intensity actions during the same time period (Mallo et al. 2009). Nevertheless, the HR profile obtained in the current study (see Fig. 1) was similar to previous reports for elite soccer referees (Catterall et al. 1993; Helsen and Bultynck 2004) with elite referees expected to cover a greater distance at a greater mean running intensity during a match (Castagna et al. 2007). However, the similar match HR profile of our sub-elite sample to elite referees may suggest that soccer referees experience similar cardiovascular stress as a consequence of both physical and psychological stresses and independently of their fitness or competitive level. Therefore, further studies should examine the magnitude and time kinetics of post-match HRV impairment and their relationships with match activities. In addition, this approach could be of great interest for post-match recovery monitoring for athletes (Halson 2011).

Interestingly, the magnitude of the night-time HRV rest-to-match day difference was similar to those studies examining post-exercise nocturnal HRV in athletes after exhausting maximal and supramaximal exercises (Hautala et al. 2001; Al Haddad et al. 2009). This is an intriguing result and confirms that referees following non-exhaustive exercise like that experienced in a soccer match, exhibited similar sympatho-vagal imbalance to that following exhaustive efforts in fitter individuals. These results raise concerns regarding the cardiovascular health of referees post-match with reduced HRV associated with greater risk of cardiovascular events (Huikuri et al. 1994) that requires further examination.

In conclusion, referees exhibited significant cardiovascular stress during a soccer match with diminished cardiac autonomic control evident in the 5 h before the match and up to 10 h post-match. In addition, those referees with a higher rest day HRV may tolerate better the physical and psychological stress before, during and after matches. Cardiac autonomic control, as assessed by HRV, may provide a simple and effective means to evaluate the psycho-physiological impact and recovery of soccer refereeing. Future studies may clarify the post-match HRV kinetics and the impact of these HRV changes on cardiovascular function and exercise performance for subsequent matches and training optimisation (Buchheit et al. 2010; Kiviniemi et al. 2007, 2010), and potential risk of overreaching/overtraining (Hynynen et al. 2008) in referees and athletes of different competitive level.

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Conflict of interest There are no conflicts of interest.

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