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Cardiac Autonomic Adaptations in Elite Spanish Soccer Players During Preseason

Daniel A. Boullosa, Laurinda Abreu, Fábio Y. Nakamura, Víctor E. Muñoz, Eduardo Domínguez, and Anthony S. Leicht

Purpose: The purpose of this study was to evaluate changes in autonomic control of heart rate (HR) and fitness in a group of elite soccer players during the preseason. ***Methods:*** Eight professional male soccer players competing in the Spanish First Division were evaluated in July (wk 1) and September (wk 8) with night-time HR variability (HRV) over 4 different days, ultra-short-term HR recovery (HRR) during a small-sided-games session, Yo-Yo Intermittent Recovery test level 1 (Yo-Yo IR1), and a field test for determination of maximum aerobic speed. ***Results:*** Players exhibited a greater HRV and a faster ultra-short-term HRR at wk 8, with the players with a lower HRV at wk 1 exhibiting the greatest improvements at wk 8. However, there were unclear improvements in performance parameters, with maximum HR (HR_{max}) being reduced over the preseason period. This change in HR_{max} was correlated with the change in short-term HRV parameters ($\rho = 0.829$, $P = .042$). Large correlations were observed among HRV, ultra-short-term HRR, and field performance parameters only at wk 8. Furthermore, the variation (%) of the root-mean-square of successive differences between R-R intervals was increased during the preseason (12.95% ± 15.14% to 29.39% ± 21.93%, $P = .013$) and significantly correlated ($r = .898$, $P = .006$) with Yo-Yo IR1 performance (~2600 ± 786 m) at wk 8. ***Conclusions:*** The current results support the appropriateness and practicality of night-time HRV and ultra-short-term HRR for evaluation of autonomic adaptations in professional soccer players, despite the unclear improvements in specific field performance parameters.

Keywords: field performance, team sports, stress, training, autonomic nervous system

Elite soccer players have exhibited remarkable aerobic and anaerobic fitness capabilities permitting them to deal with the actual physical demands experienced during matches.[1–4] In addition to the standard laboratory and field assessments, other important physiological responses have received less attention among soccer players. One example is the activity of the autonomic nervous system as assessed via heart-rate (HR) variability (HRV) analysis. There are few studies that have examined HRV changes for soccer players during training periods.[5–7] For instance, Buchheit et al[5] reported that daily changes in HRV (ie, lower coefficient of variation, CV) were significantly associated with maximal aerobic speed (MAS) in a group of young soccer players during a 3-week training camp. Subsequently, Buchheit et al[7] showed a moderate relationship among baseline HRV and maximum sprint ability, acceleration, and repeated-sprint ability in a group of young soccer players evaluated over a 3- to 4-month interval. Moreover, Buchheit et al[6] reported a relationship between exercising HR and performance improvements in a group of subelite adult players with an increased HRV after an in-season training camp in the heat. Nevertheless, night-time HRV may be a more appropriate tool for soccer-training monitoring as it is not affected by factors like emotional stress or the level of hydration that influence field HRV evaluations.[6,8,9] However, to date no studies have examined cardiac autonomic adaptations via night-time HRV analysis in elite adult soccer players.

The rate of parasympathetic reactivation (ie, HR recovery [HRR]) is another simple monitoring tool that can also identify training autonomic adaptations.[10] Specifically, a faster ultra-short-term HRR (ie, 10–20 s) has been indicative of specific autonomic adaptations for athletes of intermittent sports, probably as a result of limited recovery (<30 s) between efforts,[11] with a faster ultra-short-term HRR observed in young soccer players with greater aerobic capacity.[12] While traditional laboratory and field evaluations have been conducted in athletes,[1–4] small-sided games (SSGs) have been frequently used by coaches to concurrently enhance physical and technical capabilities of players, thus reproducing intermittent

Boullosa is with the Postgraduate Program in Physical Education, Catholic University of Brasília, Brasília, Brazil. Abreu is with Lavadores, Vigo, Spain. Nakamura is with the Dept of Physical Education, State University of Londrina, Londrina, Brazil. Muñoz is with the Faculty of Sport Sciences, University of Castilla-La-Mancha, Toledo, Spain. Domínguez is with FC Spartak Moscow, Moscow, Russia. Leicht is with the Inst of Sport and Exercise Science, James Cook University, Townsville, Australia.

match activities in a well-controlled setting.[13,14] Thus, it may be speculated that training autonomic adaptations in soccer players may be reflected by a faster ultra-short-term HRR recorded between efforts during SSGs, a more specific exercise condition than traditional evaluations. However, there are no longitudinal studies reporting ultra-short-term HRR changes after a training period.

Therefore, the aims of the current study were to evaluate the autonomic adaptations of adult soccer players to a preseason training regimen by means of night-time HRV and ultra-short-term HRR during SSGs and to explore the relationships among these autonomic indices and changes in performance parameters.

Methods

Participants

Eight Spanish First Division soccer players volunteered to participate in this study. Their characteristics are shown in Table 1. All subjects were fully informed of the experimental procedures before giving their written informed consent. The study design was approved by the local ethics committee.

Study Design and Procedures

This prospective longitudinal study was conducted over 8 weeks, with assessments conducted in the first (wk 1) and final weeks (wk 8) of the preseason (July to September) period of the 2010–11 Spanish League. A weekly training summary of preseason is shown in Table 2. Players finished the previous season 8 weeks before the start of preseason. During their holidays and after 18 rest days, they performed individually 21 conditioning sessions across 5 weeks before the start of preseason that included strength, endurance, and proprioceptive training.

Table 1 Player Characteristics

	Mean ± SD
Age (y)	24.0 ± 4.0
Height (cm)	178.3 ± 4.9
Mass (kg)	72.7 ± 7.1
Body fat (%)	10.7 ± 0.6
Number of preseason matches	6.8 ± 2.1
Preseason playing time (min)	386.9 ± 93.8

SSGs

The SSG sessions were performed after a rest day. These sessions occurred in the morning under thermoneutral conditions (ie, temperature 19–22°C; relative air humidity 63–76%) and consisted of a general warm-up, 8 versus 8 in a 50 × 52.5-m pitch, and 4 versus 4 in a 25 × 30-m pitch, with only 3 passes allowed in both SSGs to improve "technical-tactical endurance." The duration of both sessions was ~100 minutes. The players were encouraged to drink water ad libitum throughout the entire sessions. For the recording of SSG activities, the players wore a GPS device (1 Hz) equipped with a triaxial accelerometer (100 Hz; SPI Elite, GPSports Systems, Australia) in a custom backpack that was fitted with an adjustable neoprene harness. Subsequently, the data recorded were exported to the proprietary software (Team AMS software version 2.1.0.6, GPSports) for time–motion analyses. The validity and reliability of this system have been previously reported.[15] The workload of both training sessions was determined by the calculation of the mean distance covered (m) per minute, the number of accelerations per minute,[16] and the work-to-rest ratio (ie, the distance covered by the players at a velocity >8 km/h divided by the distance covered at a velocity <8 km/h), from each player's recordings.

HRR

Each individual HR recording was obtained with a transmitter (T31, Polar Electro Oy, Kempele, Finland) synchronized with the GPS unit during SSGs. HR was recorded beat by beat from the Polar HR receiver, and a

Table 2 Weekly Training Summary From Week 1 to Week 8

Week number	Total weekly training volume (min)	Total weekly sessions	Double-session days	Tactical Training		Technical-Tactical		Number of matches	Rest/travel days
				Sessions	min	Sessions	min		
1	805	11	5	3	216	3	221	0	1
2	684	11	4	0		4	247	3	0
3	541	7	2	2	180	3	226	1	2
4	668	9	2	1	90	4	262	2	0
5	681	8	3	0		5	431	1	2
6	687	10	3	0		5	372	2	0
7	438	6	0	0		4	300	1	1
8	349	5	2	0		3	249	0	4

9-point median filtering algorithm was applied to the HR data that were then averaged each second over a window size of 3.2 seconds. HRR segments were defined as any sudden and consistent decrease in HR over a predetermined period of time (≥20 s). The criteria for selection of HRR curves were an HR peak ~85% of the predicted maximum HR (HR_{max}),[10] a minimum of 20 seconds of active recovery, and a walking speed during active recovery less than or equal to ~4 km/h.[17,18]

To ensure the best fit for the rapid decrease in HR (ie, ultra-short-term HRR), linear-regression analysis was performed on all possible 5-, 10-, 15-, and 20-second-wide sections of every HRR curve. The final sections analyzed during recovery (0–10 s, 0–15 s, 0–20 s) were selected based on comparisons among the slopes and correlation coefficients of the regression lines for each single section.[19] HRR indices were calculated as absolute HR recovery (ΔHRR), the HR decrease expressed as a percentage of HR_{peak} (%HR_{peak}) at the fixed time points, and HRR index calculated using a semilogarithmic regression technique as proposed by Imai et al.[19] The natural logarithm of HR during the initial rapid decrease (ie, from the 1st to the 10th, 15th, and 20th s, respectively) was plotted against the elapsed time of active recovery, and a linear-regression analysis was applied. The time constants of the short-time postexercise HR decays or fast recovery (T_{10}, T_{15}, and T_{20}) were determined as the negative reciprocal of the regression-line slopes.

Yo-Yo Intermittent Recovery Test Level 1

The Yo-Yo Intermittent Recovery Test level 1 (Yo-Yo IR1) was administered as per guidelines[20] in conjunction with an audio player. Between each 40-m (shuttle runs of 2 × 20 m) bout, the athlete recovered with 10 seconds jogging (2 × 5 m). The validity and reproducibility of this test have been previously reported.[20] Total distance and the HR_{max} recorded during this test were considered for further analyses.

MAS

The Gacon test was used for determination of MAS and consists of running bouts of 45 seconds interspersed with walking recovery periods of 15 seconds. The first stage consists of athletes running 100 m in 45 seconds (ie, 8 km/h). The running distance is increased by 6.25 m in subsequent stages until the players cannot complete the distance in the required time. The speed of the last completed stage is calculated as the MAS and along with the HR_{max} considered for further analyses.

HRV Data Analysis

During each recording day, players wore an HR monitor (RS800, Polar Electro Oy, Finland) and were instructed to go to bed before midnight. Assessment of weekly HRV was obtained from the mean of 4 daily, continuous 3-hour night-time recordings (~midnight to 3 AM). The days were randomly selected for each player. R-R intervals 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) as previously reported.[9] Mean HR and the following HRV indices were examined: standard deviation of all normal R-R intervals (SDNN), root-mean-square of successive differences between normal sinus R-R intervals (RMSSD), low-frequency (LF; 0.04–0.15 Hz) and high-frequency power (HF; 0.15–0.4 Hz) expressed in absolute and normalized units (nu), the ratio between the LF and HF bands of the power spectral analysis,[21] the standard deviation of short-term R-R interval variability (SD1), and the standard deviation of the long-term continuous RR interval variability (SD2). The coefficient of variation (CV) of RMSSD (CVRMSSD) was calculated as[5] the average of (SD of each night-time recording/mean of each night-time recording) × 100 and regarded as an index of parasympathetic variability.

Statistical Analysis

Statistical analysis was conducted with SPSS software (v 16.02, Chicago, IL, USA). Data are presented as mean ± SD. A Shapiro-Wilk test was performed to verify the normal distribution of variables. Differences in variables between the beginning (wk 1) and the end (wk 8) of the preseason period were tested using paired Student *t* test. Relationships between parameters were identified using Pearson product–moment correlation coefficients (*r*). In cases of nonnormal distribution, Spearman correlation coefficient (ρ) was applied. The effect of preseason training on HRR at different time recovery points was examined using a 2-way analysis of variance (ANOVA) for repeated measurements (section × week) and pairwise comparisons with Bonferroni correction. Differences in regression-line slopes between selected sections of the overall HRR curves were tested using 1-way repeated-measures ANOVA. Differences in regression-line slopes between sections across weeks and among sections within weeks were assessed by the Mann-Whitney *U* test and the Wilcoxon signed-rank test. The magnitude of the changes between weeks 1 and 8 was assessed using standardized differences in means (ie, effect size, ES) and percentage of change. Threshold values for ES were 0.2 (*small*), 0.6 (*moderate*), 1.2 (*large*), and 2.0 (*very large*).[22] Confidence intervals (90%) for the true mean change or between-weeks differences were also estimated. Magnitude-based inferences were made with reference to a smallest worthwhile change calculated as 0.2 multiplied by the between-subjects standard deviation expressed as a CV. Quantitative chances of substantial positive, trivial, or negative changes were assessed qualitatively as follows: <0.5%, *almost certainly not;* 0.5% to 5%, *very unlikely;* 5% to 25%, *unlikely;* 25% to 75%, *possibly;* 75% to 95%, *likely;* 95% to 99.5%, *very likely;* >99.5% *almost certainly*. If the chances of having positive and 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: <.1, *trivial;* .1 to .3, *small;* .3 to .5, *moderate;* .5 to .7, *large;* .7 to .9, *very large;* .9 to 1.0, *almost perfect*.[22] 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 .1.[22] A *P* value of <.05 was set as the level of significance.

Results

Data from the Yo-Yo IR1 and Gacon tests are presented in Table 3. One outlier underperformed the Yo-Yo IR1 at week 8 because of physical problems (ie, pain in the hamstrings). ΔHR_{max} and the change in Yo-Yo IR1 performance over preseason were not correlated (r = –.470, P = .287). However, a moderate correlation became evident after the inclusion of the outlier (r = –.688, P = .059; Figure 1).

Night-time HRV measures at the start and end of preseason are shown in Table 4. All parameters exhibited small to moderate ES. Only SDNN and SD2 exhibited significant changes between weeks 1 and 8, with HR and LFnu exhibiting a tendency to decrease during preseason (Table 4).

HRR parameters obtained from SSG recovery periods were improved after preseason at the 20-second time point (see Table 5). Only the players (n = 6) who performed the same SSGs at weeks 1 and 8 could be considered for analysis. Under the assumption that a difference of 3.3 ± 1.7 beats/min in HRR at 10 seconds and 4.1 ± 2.3 beats/min at 20 seconds are meaningful,[11] a sample size of at least 5 players was needed to provide a power of 80% with an alpha value of .05. Sixty-four HRR curves (34 at wk 1, 30 at wk 8) with a minimum of 3 curves and a maximum of 10 curves for every single player met the selection criteria and were analyzed to find the best fit for ultra-short-term HRR. Semilogarithmic regression analysis of HR decay performed for each 5-, 10-, 15-, and 20-second window of each individual curve resulted in no significant differences among sections for the slope of regression line. Thus, we only considered 0- to 5-second, 0- to 10-second, 0- to 15-second, and 0- to 20-second sections for further analysis. The regression line of the 0- to 5-second sections presented the most level slope and the lowest correlation coefficient (.868 ± .194) compared with the 0- to 10-second, 0- to 15-second, and 0- to 20-second sections (.934 ± .079, P = .016; .934 ± .097, P = .018; and .919 ± .114, P = .076, respectively).

There were no differences between weeks 1 and 8 for all workload-related parameters during SSGs (see Table 6). HR data averaged across curves during the 20 seconds of active recovery were greater from 12 seconds onward for week 1 compared with week 8 (Figure 2a). When expressed as a percentage of HR_{peak} for each individual curve, differences became significant from 3 seconds onward (Figure 2b).

Significant and very high correlations (r > .8, P < .05) were identified between night-time HRV at week 1 and changes in HRV over the 8-week preseason, except for SDNN and SD2. In addition, ΔHR_{max} during the Yo-Yo IR1 was correlated with ΔRMSSD and ΔSD1 (ρ = 0.829, P = .042, in both cases). At the end of preseason (wk 8), Yo-Yo IR1 performance was significantly correlated with night-time HR (r = –.871, P = .011) and long-term HRV (SDNN, r = .891, P = .007; SD2, r = .924, P = .003). Furthermore, short-term HRV parameters were significantly correlated with ΔHRR at week 8 (RMSSD vs ΔHRR 10, 15, and 20 s: r = .89–.95, P < .05; SD1 vs ΔHRR at 10, 15, and 20 s: r = .83–.95, P < .05). In addition, ΔHRR at 10 and 15 seconds was correlated with MAS (r = .905, P = .035, and r = .913, P = .030).

CVRMSSD at week 1 was 12.95% ± 15.14%, while at week 8 it was 29.39% ± 21.93% (P = .013). There was a very large correlation between the CV for RMSSD

Table 3 Yo-Yo Intermittent Recovery Level 1 (Yo-Yo IR1) and Gacon Test Parameters During Week 1 and Week 8 of the Preseason

			Magnitude of Changes Between Weeks		
	Wk 1	**Wk 8**	**%Δ; ±90% CL**	**ES**	**Qualitative inference**
Yo-Yo IR1					
distance (m)	2475 ± 421	2600 ± 786	4.5; ±15.9	0.20	Unclear
HR_{max} (beats/min)	191.2 ± 6.8	179.0 ± 7.5*	–6.3; ±2.9	1.68	Almost certainly
Gacon test					
MAS (km/h)	18.1 ± 1.1	18.2 ± 0.9	0.4; ±2.5	0.05	Unclear
HR_{max} (beats/min)	193.9 ± 4.6	188.9 ± 5.7†	–2.6; ±1.5	0.96	Very likely

Note: Values are mean ± SD. Magnitudes of difference between weeks are expressed as mean percentage change (%Δ) and 90% confidence limits (±90% CL). ES, effect size; HR_{max}, maximum heart rate; MAS, maximum aerobic speed.

**P* = .004. †*P* = .013, different vs wk 1.

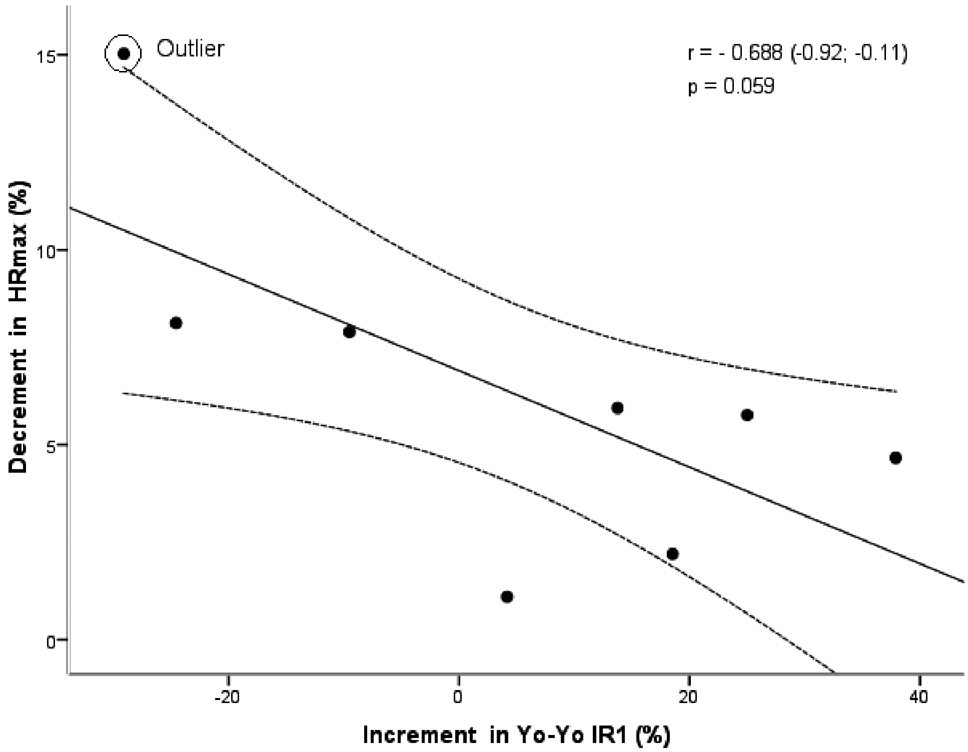

Figure 1 — Relationship between the change in maximum heart rate (HR_{max}) and the change in Yo-Yo Intermittent Recovery Test level 1 (Yo-Yo IR1) performance over preseason.

Table 4 Measures of Night-Time Heart-Rate Variability During Week 1 and Week 8 of the Preseason

			Magnitude of Changes Between Weeks		
	Wk 1	**Wk 8**	**%Δ; ±90% CL**	**ES**	**Qualitative inference**
mean RR (ms)	1208 ± 198	1319 ± 178	11.1; ±21.5	0.59	Likely
mean HR (beats/min)	51.0 ± 7.9	46.8 ± 6.1[a]	–8.1; ±7.3	0.45	Likely
SDNN (ms)	135 ± 50	163 ± 41*	31.7; ±32.9	0.61	Very likely
RMSSD (ms)	98.6 ± 80.9	116 ± 53	116; ±171	0.25	Unclear
LF (ms^2)	2591 ± 1715	3421 ± 1403	335; ±527	0.53	Unclear
HF (ms^2)	2958 ± 3456	3527 ± 2256	987; ±1701	0.19	Unclear
LF (ln ms^2)	7.5 ± 1.1	8.0 ± 0.5	10.1; ±13.6	0.64	Unclear
HF (ln ms^2)	7.1 ± 1.8	8.0 ± 0.6	20.6; ±23.0	0.68	Likely
LFnu	57.9 ± 20.7	52.4 ± 13.7[b]	–6.1; ±8.0	0.27	Possibly trivial
HFnu	42.1 ± 20.7	47.5 ± 13.7[c]	29.3; ±29.8	0.26	Likely
LF:HF	2.3 ± 2.3	1.3 ± 0.7	–15.7; ±22.1	0.59	Possibly
SD_1 (ms)	69.6 ± 57.1	82.6 ± 37.4	122; ±175	0.27	Unclear
SD_2 (ms)	174.2 ± 56.1	211.8 ± 53.1†	29.9; ±28.7	0.69	Likely

Values are mean ± SD. Magnitudes of difference between weeks are expressed as mean percentage change (%Δ) and 90% confidence limits (±90% CL). ES, effect size; RR, R-R interval; HR, heart rate; SDNN, standard deviation of all R-R intervals; RMSSD, root-mean-square of successive differences between normal sinus R-R intervals; LF, low-frequency power; HF, high-frequency power; LFnu, LF in normalized units; HFnu, HF in normalized units; SD_1, standard deviation of short-term R-R interval variability; SD_2, standard deviation of the long-term continuous R-R interval variability.

[a]*P* = .088. [b]*P* = .082. [c]*P* = .086. **P* = .017. †*P* = .023, different vs wk 1.

Table 5 Indices of Heart-Rate Recovery (HRR) Assessed During Week 1 and Week 8 of Preseason

			Magnitude of Changes Between Weeks		
	Wk 1	Wk 8	%Δ; ±90% CL	ES	Qualitative inference
ΔHRR (beats/min)					
10 s	4.4 ± 1.3	7.7 ± 3.4	101.5; ±106.6	1.26	Likely
15 s	6.7 ± 1.9	11.4 ± 4.4	94.5; ±92.3	1.40	Likely
20 s	9.3 ± 1.7	15.5 ± 4.6*	73.8; ±53.5	1.80	Very likely
$\%HR_{peak}$					
10 s	97.4 ± 0.8	95.6 ± 1.8	–1.8; ±1.7	1.25	Likely
15 s	96.1 ± 1.2	93.5 ± 2.3	–2.6; ±2.3	1.41	Likely
20 s	94.5 ± 1.2	91.1 ± 2.4†	–3.5; ±2.3	1.81	Very likely
Time constant (s)					
T_{10}	568 ± 221	342 ± 127	–29.8; ±34.9	1.25	Likely
T_{15}	518 ± 177	343 ± 106	–26.6; ±29.9	1.20	Likely
T_{20}	462 ± 68	319 ± 74#	–30.4; ±15.2	2.02	Very likely

Values are mean ± SD. Magnitudes of difference between weeks are expressed as mean percentage change (%Δ) and 90% confidence limits (±90% CL). ES, effect size; ΔHRR, absolute HRR; HR_{peak}, peak heart rate; T, fast recovery.

**P* = .039. †*P* = .025. #*P* = .01, different vs wk 1.

Table 6 Workload-Related Parameters During Small-Sided Games

	Wk 1	Wk 8	*P*
Walking speed during active recovery (km/h)	2.25 ± 0.81	2.10 ± 0.76	.489
HR_{peak} values of the selected curves (beats/min)	177.1 ± 7.9	176.6 ± 8.8	.838
Mean distance (m) covered per minute	76.7 ± 6.9	72.3 ± 6.9	.137
Number of accelerations per minute	1.74 ± 0.27	1.65 ± 0.38	.432
Work-to-rest ratio	0.65 ± 0.13	0.70 ± 0.15	.442

HR_{peak}, peak heart rate.

and Yo-Yo IR1 performance at the end of preseason (Figure 3).

Discussion

The main findings of this study are 2-fold: Indices of both HRV and ultra-short-term HRR were improved after elite-level soccer preseason training, and autonomic and performance parameters were significantly correlated at the end of preseason (wk 8). To our knowledge, this is the first study reporting simultaneously autonomic and performance parameters in elite soccer players.

Changes in HRV after preseason were only significant for overall and long-term HRV (ie, SDNN and SD2). This is a novel finding, as previous reports have observed improvements in short- and long-term HRV after different training regimens at different moments of the season in recreational runners[23] and young soccer players[5] or no changes in a group of volleyball players.[24] Since the players of our study exhibited very high physical fitness at the start of the preseason period, it may be suggested that changes in short-term HRV may be limited by the initial high fitness level as reflected in Yo-Yo IR1 values. Nevertheless, the protocol employed may have affected our results, with the low HR reflecting saturation of the HF band[25] and a limited sensitivity of this method for detecting vagal-related adaptations. Therefore, further studies should elaborate on these results via examination of different HRV protocols at different moments of the season with consideration of the magnitude of training loads.

As hypothesized, ultra-short-term HRR and T_{20} were significantly improved after the training period. This finding is important, as it reflects a greater parasympathetic reactivation during active recovery of a practical training session. This finding confirms previous observations in cross-sectional studies,[11,12] with the collective results indicating that cardiorespiratory-related adaptations could mediate running-capacity improvements of soccer players as evidenced in other studies.[1,26] Therefore, ultra-short-term HRR could provide a simple and interesting tool to monitor recovery from a currently applied training session. Nevertheless, it should be noted that the level of reproducibility of this measure under these conditions has not been determined. However, previous reports[17] of similar 60-second HRR values

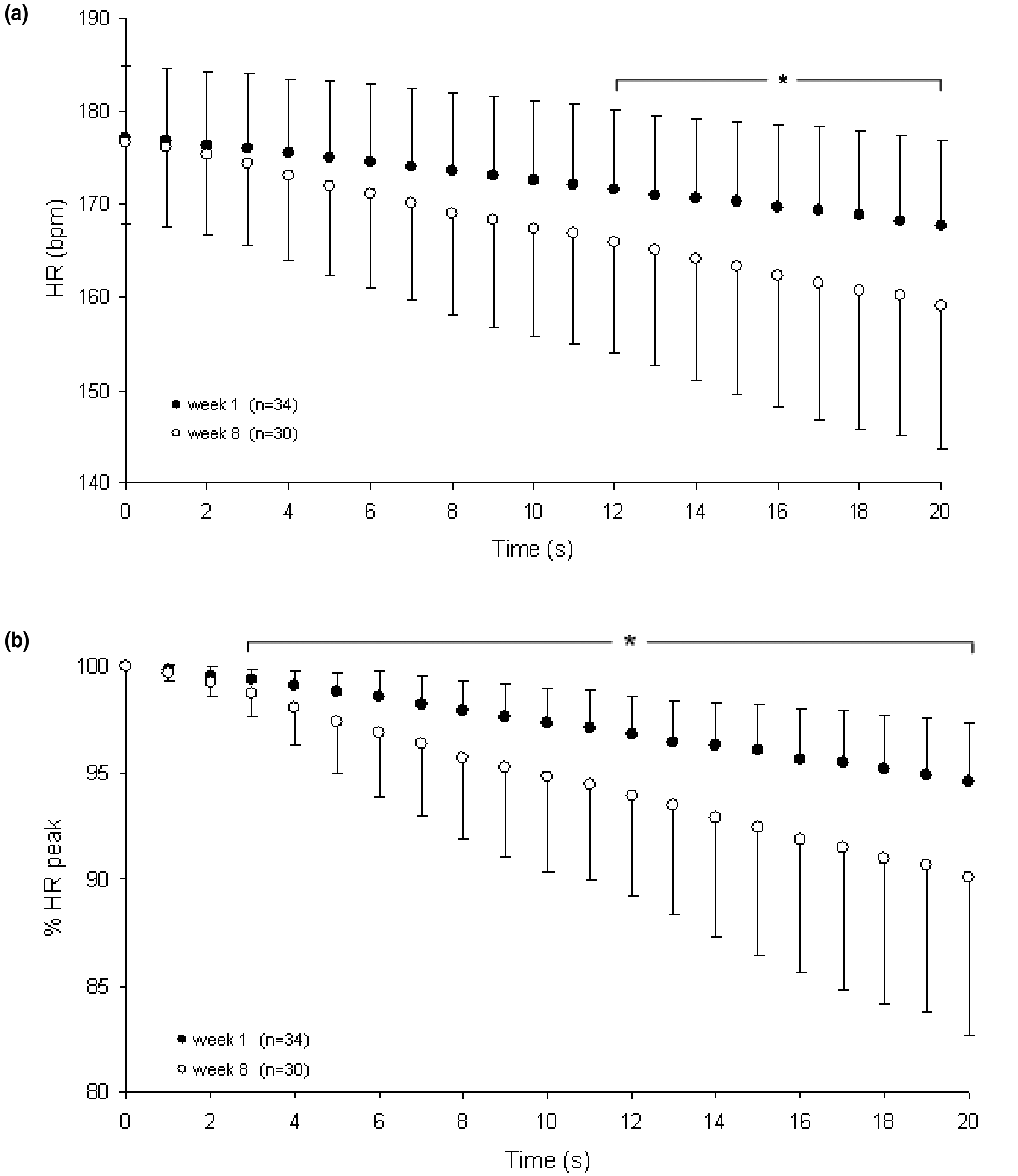

Figure 2 — Heart-rate (HR) recovery at the start (wk 1) and the end (wk 8) of the preseason during small sided games. (a) Each data point represents instantaneous HR averaged across curves for each second. (b) Data points are presented as the average percentage of HR_{peak} from each single curve. *P < .05 vs week 8.

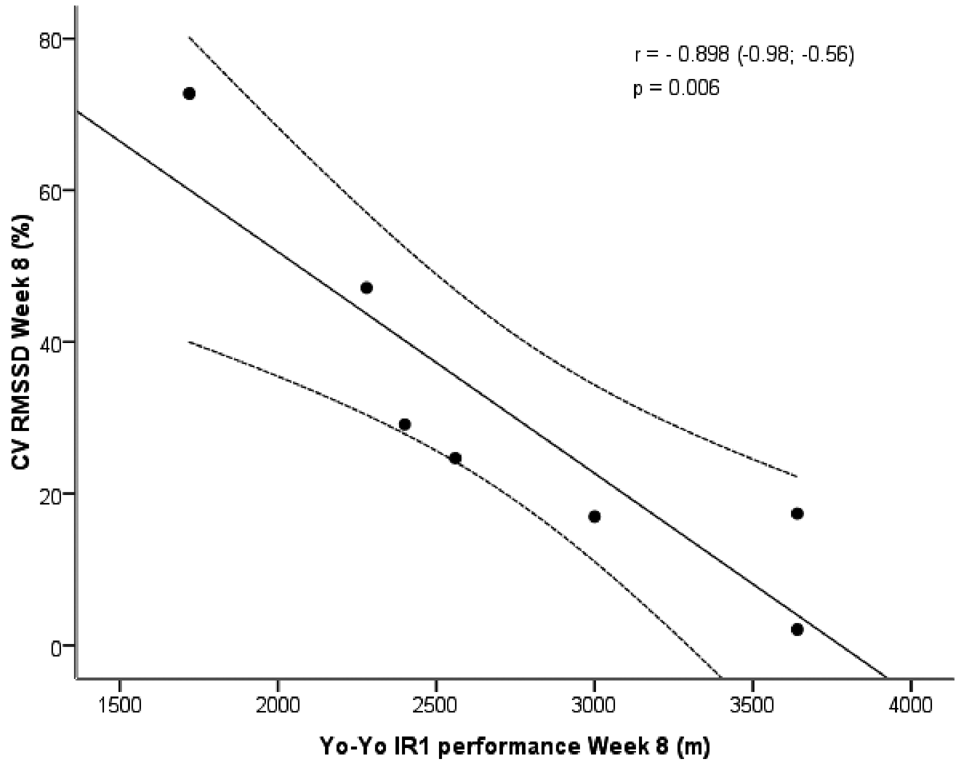

Figure 3 — Relationship between the coefficient of variation (CV) for root-mean-square of successive differences between normal sinus R-R intervals (RMSSD), and Yo-Yo Intermittent Recovery Test level 1 (Yo-Yo IR1) performance at the end of preseason (n = 7; wk 8). Data were obtained from 4 randomly selected night recordings. One outlier was excluded from analysis as he underperformed the test because of physical problems.

during walking recovery after 2 different exhausting field running protocols and similar conditions for both preintervention and postintervention evaluations most likely indicate a negligible level of measurement error.[10] In addition, greater cardiorespiratory stress during active recovery at similar velocities compared with a standing passive recovery has been reported.[18] Therefore, further studies should focus on this promising tool with special reference to active versus passive recovery, including an examination of its reproducibility and accuracy with and without the use of a GPS unit.

Medium to high correlations between HR and HRV indices, and performance in Yo-Yo IR1, and also between ultra-short-term HRR and MAS, were identified only at week 8. Furthermore, ultra-short-term HRR during SSGs and various HRV parameters were significantly correlated with each other. Previous studies have only reported low to moderate correlations between changes in HR-derived measures and field performances.[5–7] Differences between prior studies and the current study may be related to the population examined, as previous studies examined adolescent players[7] and subelite adult players.[6] In the current study, the players with greater parasympathetic modulation at week 1 also exhibited lower HRV changes during the preseason. Moreover, these correlations at week 8 but not at week 1 could explain the divergence in previous cross-sectional reports,[27] with specific fitness characteristics influencing HR and HRV and the strength of the relationships. In this regard, a possible relationship between maximal aerobic fitness (ie, VO_{2max}) and autonomic adaptations should not be discarded.[27] Further studies are warranted to determine the evolution of such parameters over the entire season, including the measurement of VO_{2max}.

A surprising finding was the large decrease in HR_{max} at the end of preseason, with previous studies reporting significant decreases in submaximal HR values at a fixed point in the Yo-Yo IR1 test.[20] Although a maximum effort during evaluations was expected, it is difficult to ascertain whether all the players did their best during physical evaluations. Previous studies have suggested that HR_{max} can be changed by up to 7% with training, tapering, or cessation of training.[28] Our results indicate a 6.3% and 2.6% decrease in HR_{max} for the Yo-Yo IR1 and the Gacon test, respectively. These differences between tests could be due to their different physiological demands and the effect of the underperforming outlier in Yo-Yo IR1 performance. However, the lowering in HR_{max} during Yo-Yo IR1 is still important if we do not consider the outlier in the analysis (ie, from 191 ± 7.3 to 181.1 ± 4.8 beats/min; ~5.1% ± 2.7%). In addition, the negative correlation between the decrease in HR_{max} and the improvement in Yo-Yo IR1 performance at the end of preseason may also suggest that players exhibiting the greatest decrements in HR_{max} may be experiencing signs of overreaching that require further confirmation. In fact, a greater fitness level would be expected over the following weeks because of the delayed training adaptations (ie, supercompensation). Furthermore, ΔHR_{max} during the Yo-Yo IR1 was also correlated with ΔRMSSD and ΔSD1, indicating that changes in HR_{max} may be mediated by neurocardiac adaptations. Further studies should clarify these adaptations and the impact they may have on aerobic-training prescription based on HR_{max} values. In addition, this finding reinforces night-time HRV as a valid monitoring tool for athletes, as it is independent of volitional responses of soccer players.

In line with recent reports in triathletes[29] and young soccer players,[5] the variation of HRV (ie, CVRMSSD) over a time period (eg, 1 wk) has been demonstrated to be a powerful tool for monitoring elite soccer players. The greater CVRMSSD at the end of preseason despite no evident changes in RMSSD was interesting and suggests a positive and possibly chaotic adaptation, with an increased responsiveness of the autonomic nervous system to daily stress-related disturbances.[5,9] In addition, in accordance with a recent study with young soccer players,[5] the high correlation detected between CVRMSSD and Yo-Yo IR1 performance at week 8 suggests that the fitter the player, the greater the exercise tolerance to training loads.[30] Given that players performed the same training loads despite improvements in fitness, it could be suggested that the lower CVRMSSD of the fitter players could be mediated by their greater recovery capacity between efforts as reflected in a faster ultra-short-term HRR. Furthermore, short-term HRV parameters and MAS were also correlated with ΔHRR at week 8. This reinforces our previous suggestion on the necessity of training-load individualization in team sports based on fitness[30] (eg, VO_{2max}). Alternatively, the lower CVRMSSD of the fitter players at week 8 may be related to a blunted capacity of high HRV values to change, as suggested by Plews et al.[29] However, it is important to note that the workloads of weeks 1 and 8 were different, with the last week of the preseason designed for supercompensation. This may have affected the increment in mean CVRMSSD observed between weeks 1 and 8, as well as the correlations observed only at week 8. However, weekly recordings were randomized, and the alternation of training workloads (eg, low- and high-intensity) was equally distributed for all the players, so it may be suggested that CVRMSSD could effectively allow comparisons between players and autonomic nervous system response to daily stresses. Further studies are needed to determine the effect of similar training loads on basal HRV at different moments of the season and to examine whether these changes are also related to CVRMSSD or similar indices obtained with other protocols over different time periods.

While the current study presents some interesting and novel results for elite players, it was limited by the number of participants due to injury, team schedules, player transfers, and commitments for monitoring top-level soccer players. These limitations support the necessity for further studies with greater sample sizes to confirm our findings in these and other team-sport players. Furthermore, we experienced difficulty obtaining a sufficient number of weekly recordings as we tried to record more recordings per week before finally achieving a minimum of 4 daily recordings for every elite athlete.

Conclusion and Practical Applications

The current results confirm that both HRV and ultra-short-term HRR were improved after elite-level soccer preseason training. Subsequently, we would recommend the use of nocturnal HRV measures to monitor training adaptations of elite athletes throughout the season. As low values of CVRMSSD may limit the sensitivity of CVRMSSD to detect changes in performance, we suggest that currently this tool may be more appropriate for evaluation between individuals, with more studies needed to examine intraindividual variation of CVRMSSD.

The analysis of ultra-short-term HRR during normal training sessions (eg, SSGs) may provide another tool to help enhance athlete performance.

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