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RESEARCH

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The relationship between resting heart rate variability and sportive performance, sleep and body awareness in soccer players

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Abstract

Background Heart rate variability (HRV) is a key marker of autonomic nervous system function and has been proposed as a tool for monitoring training adaptations. However, its relationship with performance beyond aerobic capacity remains unclear in football players. This study aimed to examine the associations between resting HRV and aerobic capacity, agility, neuromuscular coordination, sleep quality, and body awareness.

Methods Twenty-five male football players (mean age 20 ± 3 years) underwent HRV assessment via the Polar H10 system. Performance tests included the 20 m Shuttle Test (VO2max), Illinois Agility Test, Hexagon Test (neuromuscular coordination), and Vertical Jump Tests (muscular strength). Sleep quality and body awareness were assessed using the Pittsburgh Sleep Quality Index and Body Awareness Questionnaire.

Results HRV Score was positively correlated with VO2max ($r=0.4$, $p=0.04$), while LF/HF ratio showed a negative correlation with shuttle test distance (rs=-0.52, $p=0.007$). Mean RR correlated with neuromuscular coordination ($r=0.56$, $p=0.004$), sleep quality ($r=0.45$, $p=0.024$), and body awareness (rs = 0.46, $p=0.019$). No significant correlations were found with muscular strength.

Conclusions Resting HRV is associated with key performance indicators in football players, supporting its potential use in monitoring physiological readiness and training adaptations. Future research should establish reference values and evaluate HRV-based interventions for performance enhancement.

Keywords Heart rate variability, Autonomic function, Football performance, Neuromuscular coordination, Sleep quality, Body awareness

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Introduction

The proper functioning of the autonomic nervous system (ANS) is essential for athletic performance [1]. The ANS comprises two complementary parts: the sympathetic and parasympathetic systems, which must work harmoniously to maintain healthy bodily functions and homeostasis [2, 3]. Heart rate variability (HRV) is widely recognized as a practical, non-invasive method to assess ANS modulation and cardiac regulation, reflecting the balance between these two systems. It is considered a quantitative marker for assessing cardiac responses to physical and psychological stimuli [4–6].

HRV has been extensively studied in sports science due to its strong association with physiological recovery, training adaptation, and overall cardiovascular health in athletes. Elevated HRV indices indicate efficient autonomic regulation, typically seen in well-conditioned individuals, whereas low HRV may suggest autonomic dysfunction, increased stress, or overtraining [7]. Previous studies have primarily focused on the relationship between HRV and aerobic capacity, demonstrating that well-conditioned athletes often exhibit greater parasympathetic dominance at rest, which is linked to better endurance performance [8, 9]. However, HRV's role in other key performance indicators, such as agility, neuromuscular coordination, and body awareness, remains less explored.

In team sports like soccer, where rapid changes in direction, sprinting, and decision-making play crucial roles, it is critical to determine whether HRV can be a reliable marker for assessing overall athletic performance beyond aerobic capacity. Recent studies have attempted to link HRV parameters with changes in physical performance variables, but most of these have focused on runners or endurance athletes [10, 11]. Furthermore, the potential implications of HRV monitoring in practical training settings for football players have not been fully addressed.

This study aims to fill this gap by investigating the relationship between resting HRV and multiple athletic performance parameters, including agility, coordination, sleep quality, and body awareness, in football players. By establishing these relationships, this study may provide valuable insights into whether HRV can be used as a practical tool for monitoring training adaptations and optimizing performance strategies in football players. Additionally, understanding these connections could contribute to the development of HRV-based interventions for enhancing athletic performance and recovery.

Table 1 Descriptive statistics of soccer players

Variables	*n*	Mean ± SD	(95% CI)
Age (years)	25	21 ± 3	(18–22)
Height (cm)	25	181 ± 0.08	(1.78–1.84)
Body Weight (kg)	25	73 ± 7	(70–76)
BMI (kg/m^2)	25	22.4 ± 2	(21.5–23.2)
Years of training	25	12 ± 4	(10–13)

BMI: body mass index, SD: standard deviation, 95%CI: 95% confidence interval

Materials and methods

Experimental approach to problem

In the following study, football players of Ankaraspor football club in Ankara province were recruited. All measurements were collected in the field and laboratory where the football club trained. Measurements were carried out on two separate days. Athletes were allowed to rest for as long as necessary between tests by the sports club's health professionals, coaches, and conditioners. After demographic data was recorded on the first day, HRV measurement, sleep quality, body awareness, agility, and coordination tests were performed. On the second day, aerobic and anaerobic performance tests were performed.

Subjects

The study included 25 male football players with a mean age of 21 ± 3 years. The average height of the football players was 181 ± 0.08 cm, and the average body mass index (BMI) was 22.4 ± 2 kg/m^2 and average years of training was 12 ± 4. Descriptive statistics of soccer players are presented in Table 1.

Inclusion criteria were male football players aged 18–25 years, without any known systemic problems, without musculoskeletal injury in the last six months, with a football player license in Ankara province, and who volunteered to participate in the study. Exclusion criteria were caffeine consumption within the last 4 h, tobacco use within the previous 48 h, use of any drug within the last week, and consumption of alcoholic beverages within the last 24 h.

All measurements were performed at the same time of day to control for circadian influences on HRV. Players were also asked to maintain their regular sleep and dietary habits the night before testing to minimize potential confounding effects.

Ethical approval for this study was obtained from the Ethics Committee of Ankara Yildirim Beyazit University (Date-Decision No: 07.04.2022-06). The study was conducted in accordance with the Declaration of Helsinki. Additionally, after providing participants with general information about the study, their voluntary consent was secured using the 'Informed Voluntary Consent Form'.

Procedures

After recording the demographic information of the athletes, sportive performance tests, HRV measurement, sleep quality, and body awareness assessments were performed.

Sportive performance tests

40 cm Drop Jump (DJ)

For this test, which is also used as a test of the stretch-shortening cycle of the leg extensor muscles and measures the explosive strength of the athlete, the "Drop Jump (DJ)" protocol, which is available in the Optojump Next® software program (Bolzano, Bozen, Italy), which has been tested for validity and reliability, was applied [12].

Jump height and reactive force index were calculated with this system. For jump height, ground contact time (s) and flight time (s) were calculated by placing the results into the $(9.81m/s^{-1} \times \text{ flight time })^{2}/8$ equation. The equation with the system was also used for the reactive force index [13]. As suggested in previous studies, a box height of 0.4 m was used for the measurement, and participants were asked to fix their hands in the iliac crest region to minimize the effect of arm swing [12]. The test was repeated twice with 1-minute rest intervals, and the best score of these trials was used for statistical analysis.

Vertical jump test

Vertical jump height was determined using the Countermovement Jump (CMJ) and Squat Jump (SJ) protocols available in the Optojump Next® software program (Bolzano, Bozen, Italy). CMJ provides information about the lower limb's neuromuscular function and fatigue level. SJ measures the concentric force/strength of the lower limb. In addition, SJ has been used to assess the rate of force development without a tensile-shortening cycle [14]. For the CMJ protocol, the participants were asked to bend their knees 90° while keeping their chest upright during the test and then jump to the highest level they could. In the SJ protocol, in addition to the CMJ protocol, the participants were asked to bend their knees for 1.5 s until they reached 90° flexion, wait 1.5 s in a static position after their knees got 90° flexion, and then jump to the highest level they could jump. To minimize the effect of arm swing in both measurement protocols, participants were asked to fix their hands at the iliac crests, as suggested in previous studies. In both tests, any separation of the hands from the waist or bending of the knees during jumping was considered an error, and the test was repeated. Both tests were performed twice with a 1-minute rest interval, and the best score of these trials was used for statistical analysis.

Shuttle test and VO_2max assessment

For the test, which was applied to measure cardiorespiratory endurance (aerobic performance) and to estimate maximal oxygen consumption (VO_2max) levels, a 20-meter flat track prepared on a grass field was divided into eight separate corridors. The test was carried out according to a predetermined protocol, starting at 8.5 km/h, and the speed was increased by 0.5 km/h for each minute. This speed was determined by a sound signal emitted through a loudspeaker. The football players were asked to cover a distance of 20 m at each sound signal. The researchers recorded each signal captured by the athletes as a shuttle. The test was terminated for football players who could not complete the 20 m distance three times in a row or reached the exhaustion level despite the signal's sound [15]. The estimation of the athletes' VO2max levels through the values obtained from the shuttle run test was calculated using the equation proposed by Léger et al. [16]

20–30 m sprint anaerobic performance test

During the 20- and 30-meter sprint tests used to measure anaerobic performance, photocells (Microgate, Bolzano, Italy) were placed at the start line, 20 m, and finish line of the 30 m distance. Athletes performed a 5-minute warm-up exercise before starting the test, and then the test was performed when they were ready from 0.5 m behind the start line - the time on the photocells began as soon as the athlete started the test. The time at the first gate at the 20th meter and the time at the last gate at the 30th meter were recorded separately in seconds. Both tests were performed twice with a 1-minute rest interval between them, and the lowest score in seconds of these trials was used for statistical analysis [12].

Hexagon test

The Hexagon Test was performed to assess the neuromuscular coordination according to the protocols in previous studies [17, 18]. The test was performed in three repetitions, and athletes were given 1-minute rest between trials. At the end of the test, the lowest time in seconds between the three trials was used for analysis.

Illinois agility test

The Illinois agility test was performed to assess agility in a rectangular area 5 m wide and 10 m long. Photocell gates (Microgate, Bolzano, Italy) placed at the start and finish line were used for the test, and predetermined protocols were followed [19]. The test was performed in two repetitions, and athletes were allowed to rest for 1 min between trials. At the end of the test, the lowest time in seconds between the two trials was recorded.

HRV measurement

For HRV measurement, the Polar H10 (Polar Electro Oy, Kempele, Finland), a chest strap device validated to accurately assess RR intervals under resting and physical exercise conditions, was used. HRV measurement was performed in a quiet room under thermoneutral conditions (22–24 °C and 40–60% relative humidity) after the subject was lying down and rested for 5 min. Recordings were taken in the supine position with spontaneous breathing for 5 min. The electrodes on the chest strap were moistened with water at room temperature before being placed on the athletes, and the sensor was positioned on the xiphoid process of the sternum and fastened with velcro on the back of the chest strap. When a signal was detected, the Polar H10 chest strap was automatically connected and logged to the Elite HRV© (Elite HRV, Asheville, North Carolina, USA) smartphone application [20].

To control for circadian variations, all HRV measurements were performed at the same time of day (morning). Participants were instructed to follow their regular sleep schedule, refrain from consuming caffeine or alcohol, and avoid strenuous physical activity for at least 24 h before the measurement. Despite these controls, HRV recordings can still be influenced by individual physiological variations.

As short-term HRV recordings (5 min) can be affected by spontaneous breathing patterns, no fixed breathing protocol was applied to ensure ecological validity. However, participants were asked to breathe naturally and avoid exaggerated respiratory movements during the measurement.

To quantify heart rate variability, which represents the variation in the time intervals between consecutive heartbeats, the time between two R waves (RR intervals) was calculated. Analyses of HRV were conducted using two main approaches: time-domain and frequency-domain analyses.

Frequency-domain measures assess the balance of autonomic nervous system activity and include parameters such as low-frequency (LF) and high-frequency (HF) components. The LF band, which spans the 0.04–0.15 Hz range, reflects both sympathetic and parasympathetic nervous system activity, with a general emphasis on sympathetic influence. The HF band, covering 0.15–0.4 Hz, primarily represents parasympathetic activity. The absolute power of these frequency bands is measured in milliseconds squared (ms^2), and their ratio (LF/HF) provides an indication of the autonomic balance between the sympathetic and parasympathetic systems.

Time-domain measures, on the other hand, provide insights into heart rate variability through metrics derived from RR intervals. The mean RR interval represents the average time between heartbeats over the duration of the recording, while the standard deviation of these intervals (SDNN) reflects overall variability. Additionally, the root mean square of successive differences (RMSSD) between consecutive RR intervals is used as an index of parasympathetic activity, and the proportion of adjacent RR intervals differing by more than 50 milliseconds (pNN50) offers a percentage-based perspective on variability. These measures collectively allow a comprehensive assessment of autonomic regulation through both temporal and spectral dimensions [21, 22].

In addition to these conventional HRV parameters, an aggregate autonomic function index, HRV Score, was included in the analysis. HRV Score is a composite metric computed by the Elite HRV application, integrating multiple time-domain (e.g., RMSSD, SDNN) and frequency-domain (e.g., LF, HF) parameters into a single value. Higher HRV Scores indicate a predominance of parasympathetic activity and improved autonomic regulation. The validity and reliability of HRV Score as a measure of autonomic function have been supported by previous studies [23, 24]. This index provides a simplified representation of autonomic nervous system balance and has been utilized in various research settings to assess physiological readiness and training adaptations.

Pittsburgh Sleep Quality Index (PSQI)

The Pittsburgh Sleep Quality Index (PSQI), which is valid and reliable was used to assess subjective sleep quality. The PSQI is a standardized, self-administered questionnaire that retrospectively assesses sleep quality and disturbances over the past month. The PSQI consists of 7 main headings, including subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbance, sleep medication use, and daytime dysfunction, and a total of 24 questions. In PSQI, each question is scored between 0 and 3 points, and a PSQI total score ranging between 0 and 21 is obtained. A total score of >5 means "poor sleep quality," and ≤ 5 means "good sleep quality" [25].

Body Awareness Questionnaire (BAQ)

The Body Awareness Questionnaire (BAQ) was described as a tool with psychometric properties that thoroughly assessed the concept of body awareness. The scale has 40 items, each related to the name of an organ, part, or body function. The scale is a 5-point Likert-type scale and is answered as "I don't like it at all (1)", "I don't like it (2)", "I am undecided (3)", "I like it (4)" and "I like it very much (5)". The total score on the scale is scored between 40 and 200. The scale has no cut-off point; a high score is interpreted as positive body awareness, and a low score is interpreted as negative body awareness [26].

Statistical analysis

Statistical analysis was performed using IBM SPSS 24.0 (SPSS Inc, Chicago, USA). The normality of continuous variables was assessed using visual methods (histogram and probability plots) and analytical methods (Kolmogorov-Smirnov and Shapiro-Wilk tests). Normally distributed variables were presented as mean ± standard deviation (95% confidence interval), while non-normally distributed variables were summarized as median (interquartile range).

Pearson correlation analysis was used to assess relationships between normally distributed variables, whereas Spearman correlation analysis was applied for non-normally distributed variables. Correlation strength was interpreted as follows: 0.10–0.29 as weak, 0.30–0.49 as moderate, and ≥0.50 as strong [27]. A significance level of $p<0.05$ was considered statistically significant.

To further investigate the independent effects of HRV parameters on sportive performance, sleep quality, and body awareness, multiple linear regression analysis was performed. The assumptions of multiple regression, including linearity, homoscedasticity, and multicollinearity, were tested before conducting the analysis. Adjusted R^2 values were reported to indicate the explanatory power of the models.

The sample size was determined using a priori power analysis with G*Power 3.1 software. Based on a previous study examining the relationship between resting heart rate variability and the 30 m sprint test, a correlation coefficient of 0.55, an alpha error probability of 0.05, and a statistical power of 85% were used [28]. The minimum required sample size was calculated as 25 participants to ensure sufficient statistical power for detecting meaningful associations.

Results

HRV, sportive performance, sleep quality, and body awareness parameters of soccer players are shown in Tables 2, 3 and 4.

Table 2 Descriptive statistics of HRV parameters of soccer players

Variables	Mean ± SD	(95%CI)
HRV score	67.40 ± 6.67	(64.65–70.15)
RMSSD (ms)	89.27 ± 41.70	(72.06–106.49)
SDNN (ms)	132.16 ± 65.03	(105.31–159.00)
LN RMSSD (ms)	4.40 ± 0.424	(4.23–4.58)
PNN50 (%)	43.40 ± 13.55	(37.81–48.99)
Mean RR (ms)	1007.56 ± 110.16	(962.09–1007.56)
Total power (ms^2)	20373.99 ± 36077.55	(5481.91–35266.07)
LF/HF ratio	2.31 ± 2.53	(1.27–3.36)
LF power (ms^2)	50382.05 ± 198506.86	(-31557.56–132321.65)
HF power (ms^2)	5920.50 ± 10133.43	(1737.63–10103.37)
LF peak (Hz)	0.15 ± 0.192	(0.07–0.23)
HF peak (Hz)	0.25 ± 0.065	(0.22–0.27)

HRV: Heart rate variability; LF: Low frequency; HF: High frequency; SDNN: Standard deviation of the average NN ıntervals; RMSSD: Root mean square of successive differences; Pnn50: The proportion of NN50 divided by the total number of NNs. SD: standard deviation, %95CI: 95% confidence interval

Table 3 Descriptive statistics of performance parameters of soccer players

Variables	Mean ± SD	(95% CI)
Ground contact time (sn)	0.32 ± 0.06	(64.65–70.15)
Jump height (cm)	29.70 ± 5.12	(27.59–31.81)
Reaktive strenght ındex (m/s)	0.95 ± 0.20	(0.86–1.03)
Countermovement jump (cm)	32.16 ± 4.35	(30.36–33.95)
Squat jump (cm)	31.36 ± 4.67	(29.44–33.29)
Illinois agility test (sn)	16.01 ± 0.67	(17.73–16.28)
20 m sprint (sn)	3.02 ± 0.14	(2.96–3.08)
30 m sprint (sn)	4.19 ± 0.20	(4.11–4.28)
Shuttle run test distance(m)	1720.40 ± 274.17	(1707.23–1833.57)
Shuttle run test -VO_2max (ml/kg/dk)	47.72 ± 4.15	(46.01–49.44)
Hexagon test (sn)	6.34 ± 1.56	(5.70–6.99)

SD: mean ± standard deviation, 95% CI: 95% confidence interval

Table 4 Descriptive statistics of sleep quality and body perception parameters of soccer players

Variables	Mean ± SD	(%95CI)
$PSQI_1$	0.84 ± 0.47	(0.64–1.04)
$PSQI_2$	0.84 ± 0.69	(0.56–1.12)
$PSQI_3$	0.64 ± 0.91	(0.27–1.01)
$PSQI_4$	0.94 ± 1.31	(0.42–1.50)
$PSQI_5$	1.08 ± 0.57	(0.84–1.32)
$PSQI_7$	0.64 ± 0.70	(0.35–0.93)
$PSQI_{total}$	5.00 ± 2.87	(3.81–6.19)
BAQ	64.84 ± 22.23	(55.66–74.02)

PSQI: Pittsburgh Sleep Quality Index, BAQ: Body Awareness Questionnaire, SD: standard deviation, %95CI: 95% confidence interval

Relationships of HRV with sportive performance parameters, PSQI, and BAQ

The relationship between HRV parameters and sportive performance parameters is summarised in Table 5.

It was determined that there was a moderate negative correlation between HRV score, PNN50, and HF Power and agility performance ($r=-0.419$, $p=0.037$; $r=-\mathbf{0}.399$, $p=0.048$; $r_s=-0.485$, $p=0.014$, respectively); and there was a strong negative correlation between SDNN and agility performance ($r_s=-0.552$, $p=0.004$). When the correlation between HRV parameters and distance in the shuttle test and VO_2max was analyzed, it was found that there was a moderate positive correlation between HRV Score and HF Power and VO_2max ($r=0.405$, $p=0.045$; r_s = 0.401, $p=0.047$, respectively), and a strong negative correlation between LF HF Ratio and distance in shuttle test ($r_s=-0.525$, $p=0.007$). No significant correlation was found between HRV parameters and muscular strength tests ($p\geq$ 0.05). There was a strong positive correlation between mean RR and coordination ($r=0.560$, $p=0.004$).

The relationship between HRV parameters and PSQI and BAQ is presented in Table 6.

A positive and moderate correlation was found between Mean RR and $PSQI_1$ and BAQ ($r=0.450$, $p=0.024$; rs = 0.465, $p=0.019$, respectively). There was a moderate positive correlation between HRV Score and Total Power and $PSQI_5$ ($r=0.494$, $p=0.012$; $r=0.437$,

Table 5 The relationship between HRV parameters and sportive performance parameters ($n = 25$)

Variables		GCT (sn)	JH (cm)	RSI (m/s)	CMJ(cm)	SJ (cm)	IAT (sn)	20mS (sn)	30mS (sn)	20 m-SRT distance (m)	20 m-SRT VO_{2max}	HT (sn)
HRV Score	r	−0.177	0.039	0.216	−0.187	−0.045	**−0.419**	−0.309	−0.319	0.221	**0.405**	−0.102
	p	0.396	0.853	0.300	0.372	0.830	**0.037**	0.133	0.120	0.289	**0.045**	0.629
RMSSD (ms)	r	−0.158	0.052	0.198	−0.158	−0.052	−0.392	−0.235	−0.264	0.183	0.296	0.018
	p	0.451	0.806	0.342	0.450	0.805	0.053	0.259	0.203	0.382	0.151	0.933
SDNN (ms)	r_s	−0.275	−0.186	0.290	−0.070	0.143	**−0.552**	−0.363	−0.378	0.145	0.290	−0.022
	p	0.184	0.373	0.160	0.739	0.495	**0.004**	0.075	0.063	0.490	0.159	0.919
LN RMSSD (ms)	r	−0.128	0.044	0.177	−0.162	−0.018	−0.381	−0.266	−0.279	0.177	0.348	0.019
	p	0.541	0.835	0.397	0.439	0.931	0.060	0.199	0.177	0.397	0.088	0.926
PNN50 (%)	r	−0.027	0.096	0.093	−0.157	0.045	**−0.399**	−0.211	−0.196	0.276	0.380	0.095
	p	0.899	0.650	0.659	0.454	0.832	**0.048**	0.311	0.347	0.182	0.061	0.652
Mean RR (ms)	r	0.172	−0.034	−0.177	0.098	0.175	−0.037	0.066	0.074	-0.071	-0.162	0.560
	p	0.410	0.410	0.398	0.642	0.402	0.861	0.755	0.725	0.737	0.438	0.004
Total Power (ms^2)	r_s	−0.251	−0.137	0.251	−0.120	0.054	−0.384	−0.301	−0.348	0.039	0.189	−0.055
	p	0.227	0.515	0.226	0.566	0.799	0.089	0.144	0.088	0.852	0.365	0.794
LF/ HF Ratio	r_s	−0.161	−0.183	−0.025	0.063	0.039	0.209	0.047	0.028	**-0.525**	-0.383	0.056
	p	0.443	0.381	0.904	0.766	0.854	0.316	0.824	0.893	**0.007**	0.059	0.790
LF Power (ms^2)	r_s	−0.308	−0.203	0.234	−0.118	0.045	−0.272	−0.269	−0.310	-0.038	0.126	−0.030
	p	0.134	0.331	0.261	0.575	0.831	0.189	0.193	0.132	0.855	0.548	0.888
HF Power (ms^2)	r_s	−0.183	−0.020	0.330	−0.210	−0.025	**−0.485**	−0.279	−0.318	0.237	**0.401**	−0.065
	p	0.381	0.923	0.107	0.314	0.906	**0.014**	0.176	0.122	0.253	**0.047**	0.759
LF Peak (Hz)	r_s	0.152	0.083	−0.029	−0.267	−0.015	0.181	−0.024	0.005	−0.267	-0.331	0.284
	p	0.468	0.695	0.891	0.197	0.943	0.386	0.908	0.980	0.198	0.106	0.169
HF Peak (Hz)	r	−0.314	−0.136	0.198	0.053	−0.060	−0.077	−0.080	−0.086	0.360	0.218	−0.369
	p	0.126	0.517	0.343	0.802	0.777	0.713	0.705	0.683	0.077	0.296	0.070

HRV: Heart rate variability; LF: Low frequency; HF: High frequency; SDNN: Standard deviation of the average NN ıntervals; RMSSD: Root mean square of successive differences; Pnn50: The proportion of NN50 divided by total number of NNs; GCT: Ground contact time; JH: Jump height; RSI: Reactive strength ındex; CMJ: Countermovement jump; SJ: Squat jump; IAT: Illinois Agility Test; 20mS: 20 m sprint; 30mS: 30 m sprint; 20mSRT: 20-m shuttle run test, HT: Hexagon test. r= Pearson correlation coefficient; r_s: Spearman correlation coefficient

Table 6 Relationship between HRV parameters and PSQI and BAQ ($n = 25$)

Variables		PSQI $_1$	PSQI $_2$	PSQI$_3$	PSQI $_4$	PSQI $_5$	PSQI $_7$	PSQI $_{total}$	BPS
HRV Score	r	0.114	−0.013	−0.021~	−0.165~	**0.494**	−0.120	0.026	0.108~
	p	0.589	0.952	0.922	0.432	**0.012**	0.569	0.901	0.606
RMSSD (ms)	r	0.157	−0.030	−0.012~	−0.260~	**0.515**	−0.091	−0.004	0.182~
	p	0.452	0.887	0.954	0.210	**0.008**	0.665	0.986	0.383
SDNN (ms)	r_s	−0.159~	−0.155~	−0.016~	−0.116~	**0.507**~	−0.026~	−0.012~	0.151~
	p	0.447	0.459	0.938	0.580	**0.010**	0.901	0.956	0.471
LN RMSSD (ms)	r	0.200	0.045	0.008~	−0.261~	**0.515**	−0.048	0.066	0.197~
	p	0.337	0.832	0.969	0.208	**0.008**	0.820	0.754	0.345
PNN50 (%)	r	0.381	0.338	0.293~	−0.001~	0.372	0.029	0.307	0.182~
	p	0.060	0.099	0.156	0.995	0.067	0.891	0.135	0.385
Mean RR (ms)	r	**0.450**	0.215	0.172~	−0.088~	0.110	0.057	0.136	**0.465**~
	p	**0.024**	0.302	0.412	0.677	0.599	0.785	0.517	**0.019**
Total Power (ms^2)	r_s	−0.207~	−0.205~	−0.004~	−0.132~	**0.437**~	−0.084~	−0.071~	−0.047~
	p	0.321	0.325	0.985	0.530	**0.029**	0.689	0.737	0.825
LF/ HF Ratio	r_s	−0.172~	−0.390~	−0.090~	0.050~	0.007~	−0.011~	−0.190~	−0.175~
	p	0.412	0.054	0.669	0.811	0.972	0.958	0.364	0.402
LF Power (ms^2)	r_s	−0.198~	−0.214~	0.012~	−0.106~	0.361~	−0.103~	0.082~	0.093~
	p	0.342	0.304	0.954	0.612	0.076	0.625	0.697	0.660
HF Power (ms^2)	r_s	−0.225~	−0.081~	0.012~	−0.181~	0.362~	−0.095~	−0.062~	−0.091~
	p	0.279	0.699	0.954	0.388	0.076	0.651	0.768	0.664
LF Peak (Hz)	r_s	0.089~	0.224~	−0.016~	−0.128~	0.123~	−0.240~	−0.020~	−0.013~
	p	0.672	0.282	0.938	0.543	0.557	0.247	0.924	0.950
HF Peak (Hz)	r	0.090	−0.103	0.141~	0.391~	0.085	−0.126	0.179	−0.082~
	p	0.670	0.624	0.501	0.053	0.686	0.550	0.393	0.695

HRV: Heart rate variability; LF: Low frequency; HF: High frequency; SDNN: Standard deviation of the average NN ıntervals; RMSSD: Root mean square of successive differences; Pnn50: The proportion of NN50 divided by total number of NNs; GCT: Ground contact time; JH: Jump height; RSI: Reactive strength ındex; CMJ: Countermovement jump; SJ: Squat jump; IAT: Illinois Agility Test; 20mS: 20 m sprint; 30mS: 30 m sprint; 20mSRT: 20-m shuttle run test, HT: Hexagon test. r= Pearson correlation coefficient; r_s: Spearman correlation coefficient

$p = 0.029$, respectively) and a high positive correlation between RMSS, SDNN and LN RMSSD and PSQI$_5$ ($r = 0.515$, $p = 0.008$; rs = 0.507, $p = 0.010$; $r = 0.515$, $p = 0.008$, respectively).

Discussion

In this study, the relationship between resting HRV and sportive performance parameters, including aerobic capacity, agility, coordination, sleep quality, and body awareness, was examined in soccer players. The findings indicate a significant connection between these variables, while no association was found between HRV and muscular strength.

The key finding of this study is the relationship between aerobic capacity and HRV parameters HF Power and LF/HF Ratio. Among HRV parameters, HF is a marker of parasympathetic nervous system activity, while LF is a marker of sympathetic nervous system activity [29, 30]. The LF/HF ratio also reflects the sympathetic-parasympathetic nervous balance. Although LF has traditionally been considered a marker of sympathetic activity, recent studies suggest that it may also contain parasympathetic components [31]. Thus, interpreting the LF/HF ratio as a strict autonomic balance marker may be oversimplified. However, studies have shown that a reduced LF/HF ratio is associated with improved cardiovascular efficiency and aerobic performance, supporting our findings [32, 33].

The autonomic nervous system plays a crucial role in adaptation to physical exercise. It is widely recognized that elite athletes, especially endurance athletes, experience high aerobic demands and have parasympathetic nervous system dominance at rest, leading to bradycardia [34]. After chronic aerobic training, the autonomic balance shifts towards parasympathetic dominance due to increased vagal modulation and possibly decreased sympathetic activity. This study supports these findings by demonstrating a positive relationship between parasympathetic activity and aerobic performance, which aligns with previous research showing that endurance athletes have greater parasympathetic modulation and better cardiovascular efficiency [35].

Additionally, athletes with higher levels of vagally mediated HRV and cardiorespiratory fitness are known to adapt more effectively to training loads and experience lower weekly HRV fluctuations. Previous studies have reported that increased effort in performance tests, such as aerobic running tests and repeated sprint performance, is associated with improvements in HRV after exercise in young football players [36]. This study adds to the existing literature by reinforcing the notion that HRV monitoring could be a useful tool for tracking aerobic performance and training adaptations in soccer players. In practical applications, HRV-informed training modifications could assist in monitoring endurance training loads, providing insights that may help minimize the risk of overtraining and injury [37].

Another significant finding of this study is the relationship between agility and HRV parameters, particularly PNN50, HF Power, and SDNN. SDNN is an HRV index that reflects all circadian changes globally and represents overall autonomic nervous system activity. While SDNN is influenced by both parasympathetic and sympathetic stimulation, higher values are generally associated with better autonomic regulation and overall health [38, 39].

The mean SDNN value in this study was 132.16 ± 65.03 ms, which is consistent with previous research on well-trained athletes. For instance, a study by Kiss et al. identified significantly higher SDNN values (147.4 ms) in elite athletes [40]. Similarly, another study found that soccer players engaged in regular aerobic training had SDNN values of 159 ± 23.8 ms [25]. This suggests that improved endurance and training status are associated with higher SDNN values, further supporting the notion that HRV parameters can reflect an athlete's ability to cope with physiological stress [41].

Buchheit et al. suggested that a reduction in resting RMSSD, which indicates a withdrawal of parasympathetic activity, may be beneficial for performance in sports requiring high sympathetic activation, such as sprinting and change-of-direction tasks [42]. This finding aligns with our results, as we observed a significant negative correlation between HRV parameters and agility performance measured by the Illinois Agility Test. The autonomic nervous system dynamically regulates cardiovascular responses based on the physiological demands of the activity. In high-intensity, intermittent sports like soccer, temporary reductions in parasympathetic tone might facilitate rapid motor responses, improved reaction time, and enhanced neuromuscular efficiency. This may explain why athletes with lower HRV values, particularly lower RMSSD, demonstrated better agility performance.

Although HRV is commonly used as an indicator of physiological recovery and endurance capacity, its interpretation in agility-based activities requires a sport-specific perspective. In endurance sports, higher HRV is typically associated with enhanced cardiovascular efficiency and recovery potential. However, in sports involving rapid directional changes and sprinting, a certain degree of autonomic imbalance favoring sympathetic dominance might be beneficial for optimizing neuromuscular activation and reaction speed. Therefore, while HRV remains a valuable physiological marker, its role should be considered within the functional context of the sport [42, 43].

Another novel finding of this study is the relationship between mean RR interval and body awareness (BAQ score). Body awareness is closely linked to self-esteem, health-related behaviors, and overall well-being. Individuals with higher body awareness tend to engage in more health-promoting behaviors and demonstrate better physical and mental well-being. The observed association between HRV and body awareness in this study suggests that optimal autonomic nervous system regulation may contribute to heightened body awareness and interoceptive sensitivity. Previous research suggests that higher HRV is linked to improved emotional regulation and cognitive function, which may explain this relationship [44]. Additionally, the connection between HRV and interoceptive processes highlights the potential role of autonomic regulation in proprioceptive and sensory-motor integration [45].

Additionally, the autonomic nervous system shares neural pathways with sensory dermatomes, which may explain the indirect relationship between ANS function and body awareness. For example, functional disturbances in visceral organs such as the heart and stomach often manifest as discomfort or pain in dermatomally related body regions. Given that somatosensory, proprioceptive, and visual inputs are integrated at higher cognitive levels to form body representations, autonomic dysregulation could potentially impact body image and awareness.

One limitation of this study is that it exclusively included professional male soccer players. The cardiovascular training of this group may have placed them at a different metabolic and physiological level than sedentary individuals or recreational athletes, potentially limiting the generalizability of the findings. Future studies should consider including female athletes and players from various competitive levels to provide a broader perspective on the relationship between HRV and performance.

Additionally, this study did not establish causality, as it was based on correlation analyses. Although significant associations were identified, longitudinal studies with experimental designs are needed to determine whether changes in HRV parameters directly influence performance outcomes.

Another methodological limitation is that HRV measurements were conducted over a short duration (5 min) with spontaneous breathing, which may have influenced the frequency-domain parameters (especially HF power). Breathing rate is known to affect short-term HRV measurements, particularly HF power and LF/HF ratio [46]. Although we did not impose a controlled breathing protocol, participants were instructed to maintain natural breathing patterns to ensure ecological validity. Future studies should consider implementing controlled breathing conditions to improve measurement reliability.

Furthermore, this study did not include non-linear HRV measures (e.g., SD1, SD2), which have been shown to provide additional insights into autonomic control mechanisms. Non-linear HRV analysis, such as Poincaré plots or entropy measures, may offer a more comprehensive view of autonomic regulation, particularly in dynamic and high-intensity sports like football. Future research should explore the added value of these measures in tracking athletic performance and training adaptations.

Practical applications

This study highlights the relationship between HRV and key sports performance parameters, including aerobic capacity, agility, coordination, and body awareness. Given that HRV parameters reflect cardiac autonomic nervous system responses, they may serve as valuable tools for monitoring training adaptations and athlete performance.

HRV-based assessments could be integrated into training programs to optimize workload management and recovery strategies. For example, monitoring HRV fluctuations over time may help coaches adjust training intensity based on an athlete's physiological state, ultimately reducing the risk of overtraining and injury.

Although this study does not establish causality, it provides valuable insights that can inform future research on the role of HRV in sports performance. Further investigations should focus on identifying threshold values for HRV parameters to develop standardized guidelines for performance monitoring and individualized training programs.

Abbreviations

ANS	Autonomic Nervous System
BAQ	Body Awareness Questionnaire
BMI	Body Mass Index
CMJ	Countermovement Jump
DJ	Drop Jump
ECG	Electrocardiography
GCT	Ground Contact Time
HF	High Frequency
HRV	Heart Rate Variability
HT	Hexagon Test
IAT	Illinois Agility Test
LF	Low Frequency
LN RMSSD	Natural Log of Root Mean Square of Successive Differences
pNN50	Proportion of NN50 Divided by the Total Number of NNs
PSQI	Pittsburgh Sleep Quality Index
RMSSD	Root Mean Square of Successive Differences
RSI	Reactive Strength Index
SDNN	Standard Deviation of NN Intervals
SJ	Squat Jump
SRT	Shuttle Run Test
VO_2max	Maximal Oxygen Consumption

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Data availability
The data that support the findings of this study are available from the corresponding author, [RTD], upon reasonable request.

Declarations

Ethics approval and consent to participate
Ethical approval for this study was obtained from the Ethics Committee of Ankara Yildirim Beyazit University (Date-Decision No: 07.04.2022-06). The study was conducted in accordance with the Declaration of Helsinki. Additionally, after providing participants with general information about the study, their voluntary consent was secured using the 'Informed Voluntary Consent Form'.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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References
1. Daniela M, Catalina L. Effects of exercise training on the autonomic nervous system with a focus on Anti-Inflammatory and antioxidants effects. 2022;11(2).
2. Fu Q, Levine BD. Exercise and the autonomic nervous system. Handb Clin Neurol. 2013;117:147–60.
3. Besnier F, Labrunée M, Pathak A, Pavy-Le Traon A, Galès C, Sénard JM, et al. Exercise training-induced modification in autonomic nervous system: an update for cardiac patients. Annals Phys Rehabilitation Med. 2017;60(1):27–35.
4. Shaffer F, Ginsberg JP. An overview of heart rate variability metrics and norms. Front Public Health. 2017;5:258.
5. Olivieri F, Biscetti L, Pimpini L, Pelliccioni G, Sabbatinelli J, Giunta S. Heart rate variability and autonomic nervous system imbalance: potential biomarkers and detectable hallmarks of aging and inflammaging. Ageing Res Rev. 2024:102521.
6. Tekin RT, Aslan H, Uludağ V, Gümüşyayla Ş, Vural G. Novel Conservative therapies in migraine management: the impact of fascia exercises in a randomized controlled trial. J Clin Med. 2025;14(2):539.
7. Lundstrom CJ, Foreman NA, Biltz G. Practices and applications of heart rate variability monitoring in endurance athletes. Int J Sports Med. 2023;44(01):9–19.
8. Tomasi J, Zai CC, Pouget JG, Tiwari AK, Kennedy JL. Heart rate variability: evaluating a potential biomarker of anxiety disorders. Psychophysiology. 2024;61(2):e14481.
9. Mosley E, Laborde S. A scoping review of heart rate variability in sport and exercise psychology. Int Rev Sport Exerc Psychol. 2024;17(2):773–847.
10. Muñoz-López A, Naranjo-Orellana J. Individual versus team heart rate variability responsiveness analyses in a National soccer team during training camps. Sci Rep. 2020;10(1):11726.
11. Schneider C, Hanakam F, Wiewelhove T, Döweling A, Kellmann M, Meyer T, et al. Heart rate monitoring in team Sports-A conceptual framework for

contextualizing heart rate measures for training and recovery prescription. Front Physiol. 2018;9:639.
12. Montalvo S, Gonzalez MP, Dietze-Hermosa MS, Eggleston JD, Dorgo S. Common vertical jump and reactive strength index measuring devices: A validity and reliability analysis. J Strength Conditioning Res. 2021;35(5):1234–43.
13. Byrne DJ, Browne DT, Byrne PJ, Richardson N. Interday reliability of the reactive strength index and optimal drop height. J Strength Conditioning Res. 2017;31(3):721–6.
14. Riggs MP, Sheppard JM. The relative importance of strength and power qualities to vertical jump height of elite beach volleyball players during the counter-movement and squat jump. J Hum Sport Exerc. 2009;4(III):221–36.
15. Thomas A, Dawson B, Goodman C. The yo-yo test: reliability and association with a 20-m shuttle run and VO2max. Int J Sports Physiol Perform. 2006;1(2):137–49.
16. Leger LA, Mercier D, Gadoury C, Lambert J. The multistage 20 metre shuttle run test for aerobic fitness. J Sports Sci. 1988;6(2):93–101.
17. Souza AA, Bottaro M, VALDINAR A ROCHA J, Lage V, Tufano JJ, Vieira A. Reliability and test-retest agreement of mechanical variables obtained during countermovement jump. Int J Exerc Sci. 2020;13(4):6.
18. Hernández-Davó JL, Loturco I, Pereira LA, Cesari R, Pratdesaba J, Madruga-Parera M, et al. Relationship between sprint, change of direction, jump, and hexagon test performance in young tennis players. J Sports Sci Med. 2021;20(2):197.
19. MH H, Khan MH, Tanwar T, Irshad N, Nuhmani S. Acute effects of weighted plyometric exercise on sprint, agility and jump performance in university football players. Phys Activity Rev. 2021;1(9):1–8.
20. Vondrasek JD, Riemann BL. Validity and efficacy of the elite HRV smartphone application during Slow-Paced breathing. 2023;23(23).
21. Voss A, Schroeder R, Heitmann A, Peters A, Perz S. Short-term heart rate variability—influence of gender and age in healthy subjects. PLoS ONE. 2015;10(3):e0118308.
22. Laborde S, Mosley E, Thayer JF. Heart rate variability and cardiac vagal tone in Psychophysiological Research - Recommendations for experiment planning, data analysis, and data reporting. Front Psychol. 2017;8:213.
23. Naranjo Orellana J, de la Cruz Torres B, Sarabia Cachadiña E, de Hoyo M, Domínguez Cobo S. Two new indexes for the assessment of autonomic balance in elite soccer players. Int J Sports Physiol Perform. 2015;10(4):452–7.
24. Manser P, de Bruin ED. Test-retest reliability and validity of vagally-mediated heart rate variability to monitor internal training load in older adults: a within-subjects (repeated-measures) randomized study. 2024;16(1):141.
25. Buysse DJ, Reynolds CF 3rd, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh sleep quality index: a new instrument for psychiatric practice and research. Psychiatry Res. 1989;28(2):193–213.
26. Karaca S, Bayar B. Turkish version of body awareness questionnaire: validity and reliability study. Türk Fizyoterapi Ve Rehabilitasyon Dergisi. 2021;32(1):44–50.
27. Overholser BR, Sowinski KM. Biostatistics primer: part 2. Nutrition in clinical practice: official publication of the American society for parenteral and enteral. Nutrition. 2008;23(1):76–84.
28. Esco MR, Olson MS, Williford HN, Blessing DL, Shannon D, Grandjean P. The relationship between resting heart rate variability and heart rate recovery. Clin Auton Research: Official J Clin Auton Res Soc. 2010;20(1):33–8.
29. Amekran Y, El Hangouche AJ. Effects of exercise training on heart rate variability in healthy adults: A systematic review and Meta-analysis of randomized controlled trials. Cureus. 2024;16(6):e62465.
30. Tanoue Y, Komatsu T, Nakashima S, Matsuda T, Michishita R, Higaki Y, et al. The ratio of heart rate to heart rate variability reflects sympathetic activity during incremental cycling exercise. Eur J Sport Sci. 2022;22(11):1714–23.
31. Chiang JK, Lin YC. The impact on autonomic nervous system activity during and following exercise in adults: A Meta-Regression study and trial. Sequential Anal. 2024;60(8).
32. Ostrowska B, Lind L, Blomström-Lundqvist C. An association between heart rate variability and incident heart failure in an elderly cohort. Clin Cardiol. 2024;47(2):e24241.
33. Hayano J, Yuda E. Pitfalls of assessment of autonomic function by heart rate variability. J Physiol Anthropol. 2019;38:1–8.
34. Wang W, Shao M, Du W, Xu Y. Impact of exhaustive exercise on autonomic nervous system activity: insights from HRV analysis. Front Physiol. 2024;15:1462082.
35. Zaki S, Alam MF, Sharma S, El-Ashker S. Impact of concurrent exercise training on cardiac autonomic modulation, metabolic profile, body composition, cardiorespiratory fitness, and quality of life in type 2 diabetes with cardiac autonomic neuropathy: A randomized controlled trial. 2024;13(13).
36. Plews DJ, Laursen PB, Stanley J, Kilding AE, Buchheit M. Training adaptation and heart rate variability in elite endurance athletes: opening the door to effective monitoring. Sports Med (Auckland NZ). 2013;43(9):773–81.
37. Ravé G, Zouhal H, Boullosa D, Doyle-Baker PK, Saeidi A, Abderrahman AB, et al. Heart rate variability is correlated with perceived physical fitness in elite soccer players. J Hum Kinetics. 2020;72:141–50.
38. Sztajzel J. Heart rate variability: a noninvasive electrocardiographic method to measure the autonomic nervous system. Swiss Med Wkly. 2004;134(3536):514–22.
39. Cao R, Azimi I, Sarhaddi F, Niela-Vilen H, Axelin A, Liljeberg P, et al. Accuracy assessment of Oura ring nocturnal heart rate and heart rate variability in comparison with electrocardiography in time and frequency domains: comprehensive analysis. J Med Internet Res. 2022;24(1):e27487.
40. Kiss O, Sydó N, Vargha P, Vágó H, Czimbalmos C, Édes E, et al. Detailed heart rate variability analysis in athletes. Clin Auton Research: Official J Clin Auton Res Soc. 2016;26(4):245–52.
41. Costa JA, Brito J. Associations between 24-h heart rate variability and aerobic fitness in high-level female soccer players. 2022;32 Suppl 1:140–9.
42. Buchheit M. Monitoring training status with HR measures: do all roads lead to Rome? Front Physiol. 2014;5:73.
43. Dong JG. The role of heart rate variability in sports physiology. Experimental Therapeutic Med. 2016;11(5):1531–6.
44. Balaji S, Plonka N, Atkinson M, Muthu M, Ragulskis M, Vainoras A, et al. Heart rate variability biofeedback in a global study of the most common coherence frequencies and the impact of emotional States. Sci Rep. 2025;15(1):3241.
45. Candia-Rivera D, de Vico Fallani F, Boehme R, Salamone PC. Linking heartbeats with the cortical network dynamics involved in self-social touch distinction. Commun Biology. 2025;8(1):52.
46. Saboul D, Pialoux V, Hautier C. The breathing effect of the LF/HF ratio in the heart rate variability measurements of athletes. Eur J Sport Sci. 2014;14(Suppl 1):S282–8.

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