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Heart rate variability and subjective indicators of recovery in U19 soccer players

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ABSTRACT

This study aimed to investigate the relationship between heart rate variability (HRV) parameters and subjective measures of recovery in U19 elite soccer players. Eleven players (age 17.64 ± 1.03 years, weight 72.73 ± 6.05 kg, height 177.27 ± 5.83 cm) volunteered to participate. Morning HRV measures were collected using photoplethysmography via the HRV4 training smartphone application, along with daily self-reported data [fatigue levels, sleep quality from the previous night, morning mental energy, muscle soreness, and the previous day's rating of perceived exertion (RPE)]. Means and standard deviations were calculated for heart rate (HR), root mean square of successive differences (RMSSD) and natural logarithm of RMSSD (LnRMSSD), subjective responses and anthropometric measurements. Pearson product-moment correlation coefficients were used to assess the associations between HRV parameters and self-reported measures. A total of 184 HRV measurements and corresponding self-reported data were collected. The analysis revealed that both LnRMSSD and RMSSD were strongly and positively correlated with sleep quality ($r=0.66$, $p<0.01$; $r=0.55$, $p<0.01$, respectively) as well as with mental energy ($r=0.54$, $p<0.01$; $r=0.51$, $p<0.01$, respectively). In contrast, they were negatively correlated with fatigue ($r=-0.62$, $p<0.01$; $r=-0.53$, $p<0.01$, respectively) and RPE ($r=-0.45$, $p<0.01$). Self-reported variables indicated that better sleep was significantly associated with higher energy ($r=0.55$, $p<0.01$) and lower fatigue ($r=-0.56$, $p<0.01$), while greater mental energy was also linked with reduced fatigue ($r=-0.65$, $p<0.01$). Our findings suggest that daily monitoring of HRV using accessible smartphone technology may provide coaches and practitioners with a practical, non-invasive tool to track autonomic function, recovery status and training adaptations in young athletes. Integrating HRV data with subjective wellness measures could enable more individualized training prescriptions, support early detection of fatigue or overload, and ultimately optimize athletic performance.

Keywords: Autonomic regulation, Fatigue, Mental energy, Sleep quality, Stress, Football

Introduction

Heart rate variability (HRV) has emerged as a valuable measure for assessing the autonomic nervous system function, as it reflects the balance between sympathetic and parasympathetic activity (Tiwari et al., 2021). HRV is evaluated by measuring the variation between the R-R intervals, where changes in the duration of the intervals indicate altered autonomic activity (Makivic et al., 2013). Increasing evidence suggests that HRV is influenced by both physiological and psychological factors (Altini and Plews, 2021; Mirto et al., 2024), including fatigue, stress, mental energy, and sleep quality. Furthermore, research indicates that reductions in HRV reflect early autonomic changes commonly linked to infection, potentially signalling illness (Parpa et al., 2025). Subjective measures such as perceived fatigue, mental readiness and sleep quality are commonly used in sports settings to monitor recovery and well-being. Thus, exploring the association between HRV and self-reported indicators can provide a more comprehensive picture of an athlete's internal state and readiness to train or compete.

In high-intensity intermittent sports like soccer, players are frequently exposed to both physiological (Gualtieri et al., 2023; Petrov et al., 2025) and psychological stressors (Nédélec et al., 2015), including high training loads, congested game schedules, travel-related fatigue, and mental pressure. These factors may contribute to sleep deprivation or disturbances in sleep quality (Nédélec et al., 2015), ultimately affecting recovery and performance. Considering these demands, the use of accurate monitoring of both physiological and subjective perceptions of well-being is essential for guiding individualized recovery strategies, optimizing performance and reducing injury risk. HRV offers a non-invasive, time-efficient tool that, when combined with subjective data, may enhance player monitoring and optimize readiness in competitive settings.

While the association between subjective indicators of recovery and HRV has been investigated in various athletic populations, such as swimmers (Flatt et al., 2018), Nordic skiers (Schmitt et al., 2015), and soccer players (Lipka et al., 2025; Naranjo et al., 2015; Santos-Garcia et al., 2022), no studies have been identified on U19 elite players competing in the Eastern Mediterranean region. Therefore, the purpose of this study was to investigate the relationship between HRV parameters and subjective measures of recovery, such as fatigue, mental energy, sleep quality and the previous day's training rate of perceived exertion (RPE) in U19 elite soccer players. We hypothesized that HRV would be positively associated with sleep quality and mental energy in the morning and negatively associated with fatigue and the prior day's training load, supporting its role as a meaningful physiological indicator for both physical and psychological recovery.

Methods and Materials

Sampling

A priori power analysis was not conducted to determine the sample size. Instead, the study included the entire available sample of well-trained elite soccer players who met the inclusion criteria.

Eleven elite U19 soccer players (age 17.64 ± 1.03 years, weight 72.73 ± 6.05 kg, height 177.27 ± 5.83 cm) from the same team volunteered to participate. All players were starters and had participated in at least 90% of the games during the season. Non-starters were not eligible, and players who reported injuries within the past three months before the data collection were excluded. Furthermore, only players with more than three years of playing experience were eligible to participate. Although more players were initially recruited, only eleven provided sufficient subjective data and HRV measurements for analysis. Data were collected toward the end of the regular season, during the last three official games (over the period of three weeks).

Ethical considerations

The study was conducted in accordance with the Declaration of Helsinki and approved by the National Committee of Bioethics (CNBC, EEBK/ΕΠ/2024/12. In addition, all players and their legal guardians were informed of the study procedures and provided institutionally approved written informed consent.

Procedures

All players completed the anthropometric measurements and an initial briefing session. Anthropometric data included stature and body weight, measured using a wall-mounted stadiometer (The Leicester Height Measure, Tokyo, Japan) and a digital scale (Sanitas, SBF 70, Ulm, Germany), respectively. During the initial session, players were also instructed on how to download the HRV4Training application (https://www.hrv4training.com) on their phones and how to record their HRV each morning. The HRV4Training application utilizes photoplethysmography (PPG) technology to extract R-R intervals from a continuous pulse rate signal, thereby enabling the accurate measurement of HRV parameters (Altini and Amft, 2016). A familiarization session was provided to ensure players were comfortable with the procedure.

In addition to the HRV measurements, players were required to complete daily self-reported assessments of fatigue, sleep quality from the previous night, morning mental energy, muscle soreness, and the previous day's rating of perceived exertion (RPE). All subjective measures were rated using a 10-point Likert scale, where 1 indicated a minimal level (e.g., "very low" fatigue or "very poor" sleep) and 10 indicated a maximal level (e.g., "very high" fatigue or "very good" sleep quality). This approach is consistent with previous studies that have used similar Likert-type scales to quantify internal load, recovery status, and subjective well-being in athletes (Altini & Amft, 2016; Esco & Flatt, 2014).

The protocol required a one-minute HRV measurement (Esco and Flatt, 2014), performed first thing in the morning at the same time each day, in a supine position. Players were instructed to remain lying down and breathe normally during the measurement. They were also required to ensure signal quality was good; otherwise, the measurement had to be repeated. HRV was analyzed using time-domain parameters including root mean square of successive differences (RMSSD), the natural log-transformed RMSSD (LnRMSSD) and the standard deviation of N-N intervals (SDNN). Although data were also collected for pNN50 and frequency domains (LF and HF), these were not reported in this study, as accurate assessment of these parameters requires longer recording durations (Shaffer and Ginsberg, 2017).

Statistical analysis

Statistical analyses were conducted using SPSS version 28.0 for Windows (SPSS Inc., Chicago, IL, USA). Means and standard deviations were calculated for HR, RMSSD and LnRMSSD, subjective responses and anthropometric measurements. Pearson product-moment correlation coefficients were used to assess the associations between HRV parameters and self-reported measures. Correlation magnitudes were interpreted as follows: trivial (0 - 0.1), small (0.1 – 0.3), moderate (0.3 – 0.5), large (0.5 – 0.7), very large (0.7 - 0.9), nearly perfect (0.9) and perfect (1.0) (Hopkins et al., 2009). The level of significance was set at $p < 0.05$.

Findings

A total of 184 HRV measurements and self-reported parameters were collected from the 11 players. To be included in the analysis, the players had to record at least 12 HRV measurements within the period of three weeks. The anthropometric characteristics and years of playing experience of the participants are presented in Table 1.

Table 1: Anthropometric characteristics of the 11 players (mean ± SD)

Parameter	Mean ± SD	Minimum	Maximum
Age (years)	17.64 ± 1.03	16	19
Weight (Kg)	72.73 ± 6.05	64	85
Height (cm)	177.27 ± 5.83	166	183
Playing experience (years)	8.18 ± 2.14	4	11

The mean values for self-reported responses and HRV measurements are presented in Table 2, and the correlation coefficients are presented in Table 3.

Table 2: Descriptive statistics of self-reported responses and HRV measurements for the 11 players (mean ± SD)

Parameter	Mean ± SD	Minimum	Maximum
LnRMSSD (ms)	7.65 ± 0.94	5.00	11.18
RMSSD (ms)	64.41 ± 24.63	14.90	165.92
HR (beats/min)	67.23 ± 24.63	52	79
Training RPE	4.57 ± 2.31	1.00	10.00

Sleep quality	5.97 ± 2.46	1.00	10.00
Mental energy	6.04 ± 2.15	1.00	10.00
Morning fatigue	5.20 ± 2.53	1.00	10.00

Note: RMSSD: root mean square of successive differences; LnRMSSD: natural log-transformed RMSSD, HR: heart rate; RPE: rate of perceived exertion.

Table 3: Correlation coefficients between HRV and self-reported parameters

Parameter	LnRMSSD	RMSSD	RPE	Sleep quality	Mental energy	Fatigue
LnRMSSD	1	0.81**	-0.45**	0.66**	0.54**	-0.62**
RMSSD		1	-0.45**	0.55**	0.51**	-0.53**
RPE			1	-0.37**	-0.45**	0.49**
Sleep quality				1	0.55**	-0.56**
Mental energy					1	-0.65**
Fatigue						1

Note: **p<0.01; RMSSD: root mean square of successive differences; LnRMSSD: natural log-transformed RMSSD, HR: heart rate; RPE: rate of perceived exertion.

Based on the analysis, both LnRMSSD and RMSSD showed strong positive correlations ($p<0.01$) with sleep quality and mental energy. In contrast, they were negatively correlated ($p<0.01$) with fatigue and RPE. As expected, the self-reported variables demonstrated that better sleep was significantly associated with higher energy and lower fatigue, while greater mental energy was also linked with reduced fatigue. It should be noted that out of the 184 measurements, 14 were recoded while participants were sick, and three were recorded while one player was injured (minor muscle strain). In both occasions, this might have caused a reduction in HRV due to increased sympathetic activity and reduced parasympathetic activity. Also, in both conditions, this might have caused an increase in resting heart rate, which could also have resulted in reduced HRV. The statistical analysis was conducted with and without those measurements without significantly skewing the interpretation of HRV average across the dataset; therefore, the measurements were not excluded.

Discussion

This study examined the relationship between HRV and self-reported recovery metrics among elite U19 soccer players. The findings indicated that HRV, especially the LnRMSSD parameter, was positively associated with sleep ($r = 0.66$) and mental energy ($r = 0.54$). On the other hand, HRV showed a significantly negative association with perceived fatigue ($r = -0.62$) and the previous day’s training RPE ($r = -0.45$). Therefore, these findings suggest that in U19 soccer players, higher HRV was associated with better sleep and mental energy, while lower HRV was associated with greater fatigue and higher training load from the previous day.

Regarding HRV, stress and sleep, our results are in agreement with the findings of Chalmers and colleagues (Chalmers et al., 2022), who demonstrated that poor sleep quality is associated with reduced frequency domains of HRV under stress. More specifically, they (Chalmers et al., 2022) reported that the LF: HF ratio (a marker of autonomic balance) was higher during stress compared to rest, while very low frequency (VLF) and high frequency (HF) HRV were inversely related to impaired sleep during stress tasks in healthy adults. Furthermore, they found that poor sleep and greater daytime dysfunction were associated with lower VLF HRV during stress. These findings are also in agreement with those of a systematic review (Castaldo et al., 2015), which demonstrated that heart rate significantly increases during acute stress, along with increases in LF/HF ratio, reflecting sympathetic dominance under stress. Furthermore, HF HRV, which is indicative of parasympathetic activity, consistently decreases. Regarding the time-domain measures (pNN50 and RMSSD), both decrease under stress, indicating reduced vagal activity (Castaldo et al., 2015). The systematic review indicated that, despite methodological differences, there is a broad agreement that acute mental stress reduces parasympathetic activity and increases sympathetic dominance (Castaldo et al., 2015). Concurrently, evidence (Forte et al., 2019) suggests that reduced parasympathetic activity and elevated sympathovagal imbalance under stress contribute to decrements in cognition, whereas higher baseline vagal tone supports an adaptive self-regulation. More specifically, a systematic review (Forte et al., 2019) demonstrated that higher resting HRV measures (RMSSD, pNN50, HF power) are consistently associated with superior executive functioning, attentional control, working memory and cognitive function. Conversely, acute mental stress is characterized by increased sympathetic activity and reduced parasympathetic modulation, reflected in elevated heart rate, increased LF power and LF/HF ratio and reduced HF power, RMSSD and pNN50. These alternations in autonomic balance are linked to diminished mental energy and impaired cognitive efficiency (Forte et al., 2019).

A comprehensive review by Shaffer and Ginsberg (2017) highlighted that, although individual variability exists, and HRV values may differ according to age, sex, and measurement duration, reductions in HRV are consistently associated with stress, poor sleep quality, inflammation, and increased risk of mortality, underscoring the relevance of HRV assessment for both clinical and performance applications. In line with this, the association between subjective indicators of recovery and HRV has been investigated in male Division 1 sprint swimmers over a 4-week preparatory training period (Flatt et al., 2018). In that study, LnRMSSD values were significantly higher when athletes reported better-than-average sleep, lower fatigue, reduced stress and improved mood compared to worse-than-average ratings. Within-subject analyses further revealed that nearly all athletes demonstrated at least one significant relationship between HRV and self-reported recovery measures.

Similarly, a systematic review (Lipka et al., 2025) of adult soccer players demonstrated that HRV, particularly the time-domain measure RMSSD, showed significant reductions on game days and increases during recovery periods, reflecting parasympathetic withdrawal followed by reactivation. Higher RMSSD and LnRMSSD values were associated with improved performance, better recovery, and lower RPE, whereas decreases in HRV were linked to fatigue, overload and stress. The authors concluded that HRV could serve as a practical tool to monitor autonomic regulation, balance training and recovery, and potentially detect early signs of overtraining in soccer players (Lipka et al., 2025). Consistent findings were reported in a study of elite Spanish female soccer players, where HRV(RMSSD), resting HR and psychometric measures were shown to be sensitive to game and training loads, with HRV being lower on game days and rebounding in subsequent days, making them useful non-invasive indicators of recovery and fatigue status within competitive microcycles.

Result

While these associations have been documented in adult male and female soccer players, to our knowledge, no studies have investigated these relationships in U19 players competing in the Eastern Mediterranean region. Our findings suggest that daily monitoring of HRV using accessible smartphone technology may provide coaches and practitioners with a practical, non-invasive tool to track autonomic function, recovery status and training adaptations in young athletes. Integrating HRV data with subjective wellness measures could enable more individualized prescriptions, support early detection of fatigue or overload, and ultimately optimize performance.

Limitations and Recommendations

Nevertheless, the present findings are limited by the small sample size and short observation duration, which could have influenced the outcomes. Accordingly, future studies should focus on replicating these findings utilizing larger groups over longer durations. Furthermore, future studies with a greater sample size should include a multiple regression analysis to examine the extent to which subjective measures (sleep quality, mental energy in the morning, fatigue, etc) can predict HRV measures (LnRMSSD), allowing for the identification of the most influential predictors of autonomic recovery.

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Data Availability Declaration

Data Availability Upon Formal Request: While the primary datasets utilized in this study are not publicly accessible due to certain constraints, they are available to researchers upon a formal request. The authors have emphasized maintaining the integrity of the data and its analytical rigor. To access the datasets or seek further clarifications, kindly reach out to the corresponding author. Our aim is to foster collaborative academic efforts while upholding the highest standards of research integrity.

Author Contributions

Multiple Authors with Distinct Roles:

Author Contributions:

Koulla Parpa and Marcos Michaelides spearheaded the conceptualization, designed the research methodology, and supervised the entire project. Antreas Georgiadis was responsible for the data collection and analysis, and participant supervision. Marcos Michaelides, Konstantina Intziegianni and Koulla Parpa took the lead in drafting the manuscript, ensuring its alignment with scholarly standards. Karuppasamy Govindasamy contributed to the methodology and analysis and revised the manuscript for intellectual depth. All authors collaboratively discussed the results, provided critical insights, and contributed to the final manuscript. They have read, approved, and take joint accountability for the presented work's accuracy and integrity.

Author(s)' statements on ethics and conflict of interest

Ethics statement: We hereby declare that research/publication ethics and citing principles have been considered in all the stages of the study. We take full responsibility for the content of the paper in case of dispute.

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