Heart Rate Variability in Elite Team Sports: A Systematic Review

Marc Olmos-Peñarroja
marcolmospenarroja@gmail.com

INEFC: Institut Nacional d'Educacio Fisica de Catalunya https://orcid.org/0009-0002-5469-9657

Lluis Capdevila
Universitat Autònoma de Barcelona: Universitat Autonoma de Barcelona

Antonio Caparrós Pons
INEFC: Institut Nacional d'Educacio Fisica de Catalunya

Research Article

Keywords: Heart rate variability, team sports, elite athletes, autonomic nervous system, readiness, athlete monitoring

Posted Date: August 21st, 2024

DOI: https://doi.org/10.21203/rs.3.rs-4685949/v1

Abstract

Background:

Heart rate variability (HRV) is recognized as a crucial indicator of autonomic nervous system function and is valuable in sports science for monitoring athlete health and performance. This systematic review investigates the use of HRV in elite team sports to monitor training adaptations, athlete status, and overall health. The purpose is to consolidate recent findings and provide a comprehensive understanding of HRV's application in elite team sports.

Methods:

The review was conducted in accordance with PRISMA guidelines and registered in PROSPERO (CRD42023431208). A comprehensive search was performed across PubMed, Science Direct, Web of Science, and Google Scholar, covering studies from January 2013 to November 2023. Studies included involved elite team-sport athletes, with HRV measured immediately after waking. Exclusion criteria were underage athletes, injured athletes, and studies using HRV for different purposes. The review process involved screening titles, abstracts, and full texts, with a final inclusion of 12 studies.

Results:

Out of 277 identified articles, 12 studies met the inclusion criteria, involving sports such as water polo, rugby, football, basketball, volleyball, handball, futsal, hockey, and rowing. The studies highlighted HRV as a valuable tool for tracking training load adaptations, monitoring athlete readiness, recovery, and mental stress. Daily HRV measurements were commonly used, showing effectiveness in detecting overtraining and ensuring adequate recovery. Various HRV parameters and recording methods were discussed, emphasizing the need for individualized assessment. RMSSD and LnRMSSD were the most commonly used parameters, with variations in recording times and positions.

Conclusions:

HRV is an effective non-invasive marker for optimizing training regimens and improving athlete health, making it a significant tool in sports medicine. This review provides actionable insights for integrating HRV monitoring into daily training practices, ultimately enhancing athletic performance and preventing overtraining. Standardized protocols for HRV measurement are recommended to ensure consistency and reliability in data collection and interpretation. The findings highlight the need for further research to refine HRV applications and establish best practices in elite team sports.

Key Points

1. HRV is an effective, non-invasive tool for monitoring training adaptations, athlete readiness, and recovery in elite team sports, helping optimize performance and prevent overtraining.
2. Standardized protocols for HRV measurement are essential for ensuring consistent and reliable data collection and interpretation.
3. Individualized HRV assessment allows for personalized training and recovery programs, enhancing athlete health and performance

1. Background

Heart rate variability (HRV) is a simple and non-invasive method for expressing the complex and nonlinear fluctuations in the time intervals between consecutive heartbeats.[35] The mechanism responsible for regulating HRV is the autonomic nervous system (ANS), which is divided into two branches: sympathetic (SNS) and parasympathetic (PNS). HRV has been proposed as a marker of ANS status[9]. The different influences of these two systems modulate the RR intervals from the QRS complex. The SNS is responsible for variation in heart rate (HR) resulting from stress[51,52], making HRV analysis a useful method for evaluating the heart’s ability to adapt to both endogenous and exogenous loads[45,46].

HRV is shown to be a valid and highly useful tool for monitoring health in the general population. Previous studies identified the potential use of HRV for recognising healthy and diseased states. For example, the HRV indices of the PNS have been inversely associated with several risk factors, including diabetes, glucose intolerance, central obesity, dyslipidaemia and high blood pressure.[29] Furthermore, in the field of sports medicine, HRV may be used as an early-stage marker of fatigue states or overtraining.[53] HRV is therefore emerging as a key tool for tracking the time course of adaptation/maladaptation to training loads in athletes and establishing optimal training loads that lead to improved performance.[42][48] Non-functional overreaching and/or maladaptation to training loads are generally believed to be associated with lower HRV indices [31][6] while increased physical fitness[32][67] and exercise performance are more closely linked to higher HRV indices.[13][2][26] HRV is useful for assessing fatigue,[33] variation in recovery from stress,[38] stress and health[16][63] and precompetitive anxiety.[20][36] The relationship between HR and HRV with regard to intensity and training load has also been seen to be inversely proportional; i.e. HRV decreases as HR and training load increase (particularly at the start of the physical activity).[57]

There are different methods for analysing HRV, each of which provide several parameters. Currently, the most widely used methods are time-domain and frequency-domain measures, geometric measures of RR intervals and nonlinear variables:[57] SDNN (standard deviation of RR intervals) assesses the full array of cardio intervals in milliseconds, reflecting the total effect of autonomic regulation; SDANN (standard deviation of the average NN intervals) calculates the standard deviation of the average NN (or RR) intervals over 5 minutes; SDSD (standard deviation of successive RR interval differences) measures the deviation of differences between normal and adjacent cardio intervals; RMSSD (root mean square of successive differences between RR intervals) reflects parasympathetic activity;[27] pNN50 (percentage of consecutive RR intervals that differ from each other by more than 50 ms) provides information on spontaneous variations in HR;[53] and LnRMSSD (natural logarithm of the RMSSD) reflects parasympathetic cardiac modulation and may be used as a marker of fatigue.[27]

The HRV frequency spectrum is assessed using a mathematical operation, usually the Fourier transform, which decomposes the energy (power) from the RR signal into the various frequency components. These spectral components correlate to the different ANS branches. Most of the power is contained within the 0-0.4 Hz frequency band.[53] The specific components are: total power (TP) represents the variance of all RR intervals with frequency ranges below 0.4 Hz (measured in square milliseconds); high frequency (HF) reflects parasympathetic activity in bands between 0.15 and 0.4 Hz; ultra-low frequency (ULF) encompasses the frequency range below 0.003 Hz and is associated with the time-domain parameter SDANN; very low frequency (VLF) indicates hormonal, vasomotor and thermoregulatory influences in the 0.003–0.04 Hz range; and low frequency (LF) primarily reflects sympathetic activity in ranges between 0.04 and 0.15 Hz. Interpretation in this regard is controversial, as it may be attributed to SNS and/or PNS influences.[53] Geometric measures, on the other hand, are independent and based on the creation of histograms of the RR values. The geometric index of HRV is calculated from these histograms, minimising the influence of abnormal, artefact or complex ectopic RR intervals.[53]

The systems used to record HRV data range from electrocardiograms (ECG)[17][65] to more readily accessible systems such as heart rate monitors,[45][25] indirect techniques such as photoplethysmography[15][50] and ballistocardiography[24][54]. These developments in recording methodology are allowing HRV data to be obtained and analysed in a less invasive and costly manner, particularly in applied sport contexts.[39] All HR recording and analysis methods have advantages and disadvantages, which should be taken into consideration when selecting the most appropriate methodology with athletes[10]. For example, one option involves performing measurements at rest, in which case night recordings are best (more standardised)[47],[8]. However, the effects that differences in sleep patterns[43] and quality[14] have on HRV, independent of training-related changes in ANS status, have been overlooked in the literature[10]. Currently, the best practice for athletes tends to be short-term (5–10 minutes) measurements of HRV upon waking in the morning.[48][62] Such morning resting measures help overcome the limitations of night recordings and offer a certain amount of standardisation (e.g. same bed and same time most days, quiet atmosphere, no immediate effect of daily activities). This method also makes it possible to analyse the data prior to training and adjust them accordingly.[10] Such measurements may also be repeated at any time[28] to assess the ANS recovery time course following each training session/competition.[62] HRV measured during exercise has been used to assess physical fitness.[66][34] However, its practical usefulness as a tool for monitoring fitness is limited, as the determinants of HRV during exercise depend on intensity and are not exclusively ANS-related[4],58]. Furthermore, HRV has numerous post-exercise applications, including blood pressure regulation, baroreflex activity and, most importantly, post-exercise metaboreflex stimulation, which drives sympathetic withdrawal and parasympathetic reactivation[62,11]. The greater the relative exercise intensity, the greater the blood acidosis and metaboreflex stimulation, while the slower the resting heartbeat, the lower the PNS-related HRV indices. However, one of the main issues with post-exercise HRV is that it is a compound measure influenced by multiple factors[10].

With regard to recording protocols, both supine and standing recordings are commonly used within the literature[59]. However, the supine condition is better tolerated by athletes. Seated recordings are also of great interest due to their level of comfort for athletes and the fact that athletes are much less likely to fall asleep than with supine measures[10]. Since ANS activity is highly sensitive to environmental conditions (e.g. noise, light and temperature)[1], precautions must be taken to standardise recording conditions in order to isolate the training-induced effects on the ANS.

In terms of recording time, technological developments have led to shorter durations. Certain studies have demonstrated the validity of ultra-short-term measurements, e.g. a 1-minute measurement period following a 1-minute stabilisation period.[21,22] This has served to enhance the practicality of HRV data collection in team-sport athletes[30]. To lend a certain amount of credibility to the intervention, a minimum of 3 recordings per week are recommended[49]. PNS recovery has also been shown to be more rapid in highly-trained athletes compared with less trained athletes[62]. Generally speaking, a positive adaptation to training loads drives increased cardiac parasympathetic activity [60,61]. Conversely, prolonged overreaching decreases this activity and, as a result, leads to higher sympathetic modulation[38,59]. These adaptive responses may vary from one subject to the next, which suggests that professionals should monitor variables that reflect each subject's capacity to respond to a specific training stimulus[5]. While there is currently little evidence as to which variable is best for monitoring fatigue and adaptations in athletes[64], the use of HRV to monitor changes in ANS activity is a promising tool for reflecting responses and adaptation to training programmes[10].

2. Methods

This systematic review was recorded in PROSPERO (registration number: *CRD42023431208*) and communicated in accordance with the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA)[44]. Due to the methodological and statistical heterogeneity of the studies included, a descriptive approach was adopted in the research synthesis[56].

2.1 Admissibility criteria

We conducted a search for articles published between 2013 and 2023 that used the variable "heart rate variability" (HRV) immediately after waking as a tool for monitoring athletes.

Only those studies performed with elite team-sport athletes were selected. Any studies involving underage athletes or athletes with some kind of injury were excluded, as were those which used HRV for different purposes.

2.2 Source of information

We performed a systematic search across the following databases: PubMed, Science Direct, Web of Science and Google Scholar. The period of study included all articles published between 1 January 2013 and 30 November 2023.

2.3 Search strategy

The search strategy included both controlled vocabulary and free-text terms. The terms used were "heart rate variability", "team sports" and "readiness" (see Table 1).

Table 1
Search strategy

Database SearcH	Search Terms
PUBMED	(((("Heart Rate Variability"[Title/Abstract] OR HRV[Title/Abstract] OR "variability index"[Title/Abstract]) AND ("team sports"[Title/Abstract] OR "team sports performance"[Title/Abstract] OR readiness [Title/Abstract])))
SCIENCE DIRECT	Tittle: (("Heart Rate Variability" OR HRV OR "cardiac variability" OR "heart rate variability index") AND ("team sports" OR "team games" OR "team sports performance" OR Readiness))
GOOGLE SCHOLAR	(HRV OR Heart Rate Variability) AND Readiness AND "Team Sports"
WEB OF SCIENCE	AB=((("Heart Rate Variability" OR HRV OR "cardiac variability" OR "heart rate variability index") AND ("team sports" OR "team games" OR "team sports performance" OR Readiness)))

2.4 Study selection and data collection process

All identified references were imported into the Mendeley Reference Manager v2.106.0 and all duplicates were removed. Two researchers conducted the review process, which was divided into three phases. As a first step, the authors screened the titles, abstracts and keywords from the pertinent studies. As a second step, they screened the full articles, while step three involved searching for other articles on heart rate variability and readiness from the references listed in the review articles. They found 4 articles of interest, two of which did not use HRV for the purpose of assessing athlete readiness. The authors discussed the areas of disagreement and included only two of these articles.

They then devised a protocol for extracting data from the articles (See Fig. 1). They extracted information about the article (author, year of publication), the subjects (number, sex, average age and sport), the duration of the intervention, the recording method, the variables, the parameters used for the analysis and the objective of the study. (See Table 2).

Table 2
Summary and results of twelve studies reviewed

Study	Sample analysed	Intervention duration	Recording method	Variables	HRV parameters	Objective
D'Ascenzi et al., 2013	10 female volleyball players with an average age of 26.9 +- 4.5 years	3 days	Data recorded one and two days prior to the match and the day of the competition. Measurements performed immediately after waking, between 7–8 a.m., for 10 minutes, after 5 minutes of supine rest. Recordings obtained using MINIcardio Pro heart rate monitors.	Performance indicators while serving and receiving, HRV.	Time-domain: STD, RMSSD, pNN50 Frequency-domain: Spectral response (VLF, LF, HF), total power, lnVLF, lnLF, lnHF, LF%/HF%, Poincaré plot: SD1 spread, SD2 on x-axis, SD1/SD2. Total standard deviation of SD1 and SD2. Minimum HR, maximum HR and average HR.	To monitor player status (mental stress)
Bellenger, C. et al., 2022	11 water polo players with an average age of 28.8 +- 5.3 years	16 weeks	Daily recordings. Measurements performed during overnight sleep period using WHOOP heart rate monitors.	HRV, HR, training load (total cardiovascular load assessed by WHOOP device) (Scale 0–21)	LnRMSSD and standard deviation (%)	To monitor player status (readiness)
Botonis, P. et al., 2021	9 water polo players with an average age of 25.6 +- 4.7 years	9 weeks	Data collected 3 days a week (4 days during regeneration week), 30 minutes after waking (prior to training), in the training facilities (without food or coffee). Measurements performed for 3 minutes, after one minute for stabilisation, seated. Recordings obtained using Polar heart rate monitors.	HRV, perceived recovery status (0–10), RPE	LnRMSSD and LnRMSSDcv	To track adaptations to training
Chrismas B. et al., 2019	6 football players with an average age of 26 +- 2 years	4 months	Data collected on training days. Measurements performed 30–45 minutes prior to training in a room with a standardised temperature, seated, for 1 minute, with a respiratory rate of 7.5 breaths per minute (rate set by app). Recordings obtained using Polar heart rate monitors and the ithlete app.	HRV, external load (TD, high-speed distance, high metabolic load, ED (intensity at which total distance is covered) and equivalent distance index (ratio between ED and TD)).	LnRMSSD (weekly average)	To monitor player status (readiness)

HRV Heart Rate Variability, *STD* standard deviation, *RMSSD* root mean square if differences of successive intervals, *pNN50* percentage of adjacent NN intervals differing by more than 50 ms divided by the total number of al NN intervals, *VLF* very low frequency, *LF* low frequency, *HF* high frequency, *HR* heart rate, *SD* standard deviation, *LnRMSSD* logarithm of the root mean square of successive RR interval differences, *RPE* rate of perceived exertion, *LnRMSSDcv* coefficient of variation logarithm of the root mean square of successive RR interval differences, *ED* Equivalent distance, *TD* Total distance, *SDSD* standard deviation of successive differences, *SDNN* standard deviation of NN intervals,

Study	Sample analysed	Intervention duration	Recording method	Variables	HRV parameters	Objective
Flatt A. & Howells D., 2019	12 rugby players	3 weeks	Daily recordings. Measurements performed immediately after waking (prior to consuming food or fluids), for 1 minute, seated, under spontaneous breathing conditions. Recordings obtained using Polar heart rate monitors and the Elite HRV app.	Maximum aerobic speed, wellness questionnaire, HRV, external training load (total distance covered, high-speed distance, number of accelerations and decelerations), internal training load (RPE)	LnRMSSD (weekly average and standard deviation)	To track adaptations to training
Grainger A. et al., 2022	13 rugby players with an average age of 27 +- 4 years.	10 weeks	Daily recordings. Measurements performed between 8–10 a.m., post bladder emptying, prior to exercise and with no caffeine for previous 12 hours, in supine position. Recordings obtained using an Omegawave ECG1A device.	HRV, state of central nervous system assessed using the Omegawave device's direct current potential option (scale 1–7), self-report wellness questionnaire (0–50)	SDNN, SDSD, RMSSD, LF, HF, total power (variance of all normal-to-normal intervals in frequency range of 0-0.4)	To monitor player status (recovery status)
Holmes C., et al., 2020	16 hockey players and 47 female rowers	17 weeks	Daily recordings. Data from hockey team recorded upon waking, at home, using the ithlete app and a fingertip optical heart rate monitor. Data from rowers recorded upon waking, at home or at training facilities, using the HRV4Training app and by placing a finger on the mobile telephone's camera.	% of days on which the athletes measured HRV	-	To monitor player status (recovery status)
Nakamura F. et al., 2015	24 futsal players with an average age of 22.9 +- 4.2 years	7 weeks	Data collected on first day of the week, after 48 hrs of rest, at the futsal gym, in a fasted state for two hours and free of caffeine or alcohol for 24 hours. Measurements performed for 1 minute, seated, under spontaneous breathing conditions. Recordings obtained using Polar heart rate monitors.	HRV	RMSSD, lnRMSSD	To track adaptations to training
Nakamura F. et al., 2016	40 rugby players with an average	4 days	Data collected twice on the first day, at 10 minutes intervals, and once on all other	HRV	LnRMSSD	To track adaptations to training

HRV Heart Rate Variability, *STD* standard deviation, *RMSSD* root mean square if differences of successive intervals, *pNN50* percentage of adjacent NN intervals differing by more than 50 ms divided by the total number of al NN intervals, *VLF* very low frequency, *LF* low frequency, *HF* high frequency, *HR* heart rate, *SD* standard deviation, *LnRMSSD* logarithm of the root mean square of successive RR interval differences, *RPE* rate of perceived exertion, *LnRMSSDcv* coefficient of variation logarithm of the root mean square of successive RR interval differences, *ED* Equivalent distance, *TD* Total distance, *SDSD* standard deviation of successive differences, *SDNN* standard deviation of NN intervals,

Study	Sample analysed	Intervention duration	Recording method	Variables	HRV parameters	Objective
	age of 25.4 +- 5 years.		days between 8–9 a.m., at the facilities, in a fasted state and free of caffeine or alcohol for 24 hours. Measurements performed for 2 minutes, seated, under spontaneous breathing conditions. Recordings obtained using Polar heart rate monitors.			
Milanez V. et al., 2015	14 handball players with an average age of 26 +- 4.6 years.	3 weeks	Data collected during the last training session (Friday) and first training session of the week (Monday). Measurements performed for 10 minutes (of which the last 5 minutes were analysed), prior to training, seated, under spontaneous breathing conditions. Recordings obtained using Polar heart rate monitors	DALDA questionnaire, RPE, HRV	RMSSD, SDNN	To monitor player status (recovery status)
Moreno J. et al., 2015	6 basketball players with an average age of 20 +- 2.28 years	One season of Spain's second division basketball league (Leb Oro)	Data collected on training days. Measurements performed prior to training, between 8–10 a.m. (in a fasted state), for 5 minutes, in supine position, under spontaneous breathing conditions. Recordings obtained using a microchip accelerometer and mobile app developed specifically for the study.	Perceived recovery scale (TQR), HRV	Average RR, average HR, SDNN, RMSSD, pNN50, LF/HF	To monitor player status (recovery status)
Ravé G. et al., 2020	14 football players with an average age of 27.9 +- 4.3 years	12 days	On match day, at 8:30 a.m. (before breakfast). Measurements performed for 10 minutes, in supine position, followed by 7 minutes of standing, without speaking or moving.	HRV monitored with an orthostatic test, perceived physical fitness (visual analogue scale)	RMSSD, spectral power (very low, low and high frequencies), LF/HF ratio, total power (HRV), LF and normalised HF power (Lfnu and Hfnu)	To track adaptations to training

HRV Heart Rate Variability, *STD* standard deviation, *RMSSD* root mean square if differences of successive intervals, *pNN50* percentage of adjacent NN intervals differing by more than 50 ms divided by the total number of al NN intervals, *VLF* very low frequency, *LF* low frequency, *HF* high frequency, *HR* heart rate, *SD* standard deviation, *LnRMSSD* logarithm of the root mean square of successive RR interval differences, *RPE* rate of perceived exertion, *LnRMSSDcv* coefficient of variation logarithm of the root mean square of successive RR interval differences, *ED* Equivalent distance, *TD* Total distance, *SDSD* standard deviation of successive differences, *SDNN* standard deviation of NN intervals,

Study	Sample analysed	Intervention duration	Recording method	Variables	HRV parameters	Objective
			Recordings obtained using Polar heart rate monitors.			

HRV Heart Rate Variability, *STD* standard deviation, *RMSSD* root mean square if differences of successive intervals, *pNN50* percentage of adjacent NN intervals differing by more than 50 ms divided by the total number of al NN intervals, *VLF* very low frequency, *LF* low frequency, *HF* high frequency, *HR* heart rate, *SD* standard deviation, *LnRMSSD* logarithm of the root mean square of successive RR interval differences, *RPE* rate of perceived exertion, *LnRMSSDcv* coefficient of variation logarithm of the root mean square of successive RR interval differences, *ED* Equivalent distance, *TD* Total distance, *SDSD* standard deviation of successive differences, *SDNN* standard deviation of NN intervals,

3. Results

3.1 Study selection

The initial compilation of articles for this review contained 277 potentially relevant publications. After removing 29 duplicates (10.5%) and screening the remaining titles, 53 publications (19.1%) were accepted for full text screening. Of these, 43 (81.1%) were rejected due to non-compliance with the admissibility criteria: using a sample containing athletes under 18 years old (n = 10), studies not involving team sports (n = 20), using a sample containing unhealthy athletes (n = 3), not using elite athletes (n = 3) or using HRV for purposes other than those considered in this review (n = 7). Following the full text screening, the possibility of adding 4 publications from the references listed in the included articles was considered, of which 2 were rejected for not using HRV for the same purposes as in this review. Ultimately, 12 articles were included in the review (see Fig. 1). All the selected studies focus on interventions that analyse resting HRV prior to any physical activity. The subjects in all the studies are elite team-sport athletes and are all of legal age (see Table 1).

One of the characteristics of the studies analysed in the review are their small sample size, with a number of subjects oscillating between 6 and 63, all of whom are under the age of 35. Most include less than 15 athletes (n = 9) and less than half include women (n = 2). Of the 12 publications that were analysed, 2 were conducted with water polo players,[3][7] 3 with rugby players [23,27,41] 2 with football players[18,55], 1 with basketball players[39], 1 with volleyball players[19], 1 with handball players[37], 1 with futsal players[40] and 1 with both hockey players and rowers[30]. As regards intervention duration, the selection includes studies that were performed over periods of less than 2 weeks (n = 3), 2–8 weeks (n = 3) and more than 8 weeks (n = 6).

3.2 Objective of the intervention

The studies may be divided into two groups based on their main objective: 1) those that use HRV to track adaptations to training loads; and 2) those that use HRV to monitor athlete status. The first group contains 5 studies (41.6%). The second group is further divided into 3 subgroups, which include 2 studies in which HRV is used as a marker of athlete readiness (16.6%), 4 studies whose purpose is to determine the athletes' recovery status (33.3%) and 1 study that uses HRV to measure the players' mental stress (8.3%).

3.3 Recording method

In half the studies, HRV was measured daily (n = 6), while in the rest of the publications, such data was collected on training days only (n = 2), the first day of the week (n = 1), the first and last training session of the week (n = 1), match day (n = 1) or 3 days a week (n = 1). The recording time ranges from 1 minute to a full night: 5 studies used recordings of 3 minutes or less (41.6%), 5 used recordings of 5 minutes or longer (41.6%), one recorded throughout the night and 2 articles did not specify the recording time. Most recordings were performed in the morning (n = 8), with 5 studies specifying that the athletes were in a fasted state; others were conducted prior to training (n = 3); and in one study data was collected throughout the night. In terms of recording position, 6 studies used a seated position (50%), 4 used a supine position (33.3%), 1 used two positions, supine and standing (8.3%), and 1 publication did not specify the recording position (8.3%). With regard to measurement devices, most studies used Polar heart rate monitors (n = 7), although other devices were also used, such as WHOOP (n = 1), Omegawave (n = 1), MiniCardioPRO (n = 1), an optical fingertip sensor (n = 1) and a microchip accelerometer (n = 1). In addition, certain studies used mobile apps to record data: 2 studies used ithlete, 1 Elite HRV, 1 HRV4Training and 1 an app created specifically for the study.

3.4 HRV parameters used

The root mean square of successive differences between cardio intervals was the most commonly used parameter for measuring HRV. Half the articles (n = 6) used it directly, while the other 6 used derived parameters such as natural logarithm (Ln) or standard deviation (CV) from this parameter. Standard deviation of the full range of cardio intervals (SDNN), standard deviation of the differences between normal and adjacent cardio intervals (SDSD), low frequencies (LF), high frequencies (HF), the percentage of consecutive RR intervals that differ from each other by more than 50 ms (pNN50) and mean standard deviation (STD) are some of the other parameters used in the analysed studies.

4. Discussion

This systematic review has shown that heart rate variability (HRV) is monitored primarily for the purpose of assessing adaptations to training loads and monitoring athlete status, determining their readiness, recovery status and level of mental stress. In this regard, HRV emerges as a valuable tool for evaluating the impact of the athletes' physical training[19] and recovery[37]. In addition to assessing physical fitness, HRV also provides information on player readiness[18,19]. In short, HRV has great potential as a marker of readiness in team sports[55] and may anticipate problems such as delayed recovery or reduced sleep quality during periods of high training loads or competitive stress[19].

4.1 Variables

Two main parameters were used in the reviewed studies: RMSSD and LnRMSSD. RMSSD is correlated with perceived physical fitness in team sports, making it a useful marker for assessing adaptation to training loads[55]. Furthermore, the weekly assessment of mean HRV values and their daily fluctuation (quantified using the coefficient of variation, CV) are sensitive to training load.

Nonetheless, assessed weekly, the coefficient of variation of LnRMSSD (LnRMSSDcv) may be even more sensitive to training responses than mean LnRMSSD (LnRMSSDm)[23]. It has been shown that the weekly mean and standard deviation of LnRMSSD may be calculated from three randomly selected days from within the same week[41]. Another variable that should be taken into account is VLF percentage (VLF%), as increases in this value may be a highly sensitive parameter for perceiving changes in ANS activity induced by precompetitive stress[19].

4.2 Data collection

Overall, heart rate monitors were the most commonly used device for measuring HRV in the analysed studies. They were often combined with apps and/or software to obtain HRV values. Smartphones are particularly advantageous, as HRV may now be measured without the need for electrocardiography equipment.[18] The "ithlete" app for tablets is an example of this methodology, which is cost-effective and easy to use[18]. One of the alternatives to heart rate monitors is ballistocardiography. This method serves to record HRV in applied contexts, avoiding the use of heart rate monitors and chest straps with electrodes or other external sensors[39]. It is extremely important to take day-to-day variability into consideration with repeated HRV recordings. This refers to the reproducibility of an observed value when a measurement is repeated. Day-to-day variability makes it possible to separate a "true" change in a given variable from the inherent "noise"[3]. For example, the day-to-day variability in HRV measured using a WHOOP heart rate monitor is 5.5%, which suggests that it may be a good tool for assessing readiness in athletes[3]. Another study shows that recording HRV values with a mobile telephone is a practical, ecological and valid tool for monitoring readiness in individual players[18].

Another factor that should be taken into account when collecting data are the recording conditions (time of day, temperature, position, light, etc.) during HRV assessment. Unfortunately, the lack of standardisation of HRV measures within the literature could lead to a misinterpretation of the findings.[18] To guide training methods and loads, coaches and sport scientists could consider daily HRV assessments. For example, measuring HRV every morning after waking could help rapidly identify changes in cardiac autonomic regulation[40]. It is also important to educate athletes about the purpose of monitoring tools and provide a clear explanation about HRV in order to improve long-term compliance rates. Since the recommended procedure involves measuring HRV several times a week to account for daily fluctuations and obtain more precise insight into the recovery status of athletes, coaches must make efforts to keep the level of motivation among their players high. Coaches and practitioners interested in implementing sports monitoring tools such as HRV should design a data collection process that is easy to implement and is based on short-term recordings[30].

In the analysed articles, the duration of the HRV recordings ranged from 1 minute to a full night. Collecting the lnRMSSD in a 1-minute window is capable of showing meaningful alterations in the physiological state in the same direction and magnitude as the lengthier traditional procedure[40]. Therefore, to simplify monitoring, the recommended procedure involves acquiring RR intervals in only 1 minute, preceded by 1 minute for stabilisation, with the subject in seated position at rest. This makes it possible to monitor lnRMSSD on a daily basis and assess training effects[40]. While supine RMSSD only moderately correlates with perceived physical fitness in football players, larger correlations were observed for other supine and standing HRV indices, such as TP in standing position and LF in supine position. Yet despite this, there are still doubts within the literature with regard to position in the moment of recording. Ravé et al. (2020) argues that HRV in standing position could be a good monitoring tool in sports that require simultaneous capacities[55].

Regarding the reliability of repeated assessments, the literature shows that short-term inter-day and intraday lnRMSSD measures in elite sports are repeatable[41]. The intraday reliability of ultra-short-term measures is higher than inter-day assessments, as intraday conditions ensure a more uniform environment and more consistent physiological and psychological states[41]. As a result, Nakamura et al. (2016) supports the use of the ultra-short-term assessment method in highly trained team sports.

4.3 Data interpretation

Once the HRV values have been obtained, they must be adequately interpreted. Several studies concur that HRV should be taken into consideration as an individual marker[39,18] in the recovery process[39]. The large individual differences that exist in autonomic changes suggest that athlete heterogeneity should be an important consideration when using HRV measures. HRV should therefore be interpreted carefully alongside other measures, yet most importantly at individual level and compared to their own "baseline" (obtained from multiple measures to establish "normal" measure variation)[18]. It is important to bear in mind that HRV parameters appear to show specific patterns for each player[39] and that changes in HR indices may be due to isolated training sessions or, perhaps, in response to a training phase. Consequently, it is crucial to emphasise the individualised nature of HR data[27]. According to Grainger et al. (2022), HRV parameters decrease following periods of higher training or competition load. Furthermore, time-domain measures appear sensitive to match-day loads, and reductions in post-match HRV coincide with reductions in self-reported perceptions of recovery[27]. It should also be pointed out that increased sympathetic activity, assessed by HRV, could have a negative effect on sports performance[19]. Consideration should also be given to the potential influence of player anxiety prior to competition on HRV recordings[55]. Other studies indicate that players benefit significantly from passive rest over a typical weekend without scheduled matches. This translates into increased HRV indices[27,37] and reduced perceived stress symptoms[37]. However, it is crucial to understand that muscle soreness recovers at a slower time course than ANS responses, which may lead to an incorrect assessment of player readiness[27]. According to Chrismas et al. (2019), when players are more "recovered" (as demonstrated by a higher HRV), they are able to express higher Equivalent Distance Index (EDI) values[18]. In short, HRV may be a valuable indicator for assessing recovery and state of readiness in players. Yet these values must be interpreted at the level of the individual[18,27,37].

Long-term observations show that a 30% reduction in the in-season training load led to a meaningful increase of LnRMSSD and improved perceived recovery status[7]. Furthermore, as observed in Flatt & Howells (2018), individuals who experienced less fluctuations in LnRMSSD during intensified training responded more favourably to stimuli[23]. Individuals who exhibited a smaller LnRMSSDcv during the initial spike in training load displayed more favourable changes in running performance and vice-versa[23]. In conclusion, LnRMSSDcv did not display a linear dose-response relationship with the training load. In fact, it appears to reflect an adaptive physiological response to the imposed training stimulus, which may be useful for identifying individuals who respond undesirably to training[23]. Another important aspect of HRV interpretation is the presence of non-training stressors, such as travel or days off, which may result in a lack of correlation between RPE (rate of perceived exertion) and the LnRMSSD. However, this aspect is inherent to the competition schedule of elite-level teams and must be taken into consideration[7]. With regard to athletic performance, the studies show that there may be an inverse correlation between the technical ability marker and the LF/HF% ratio (ratio of low frequency to high frequency). This suggests that an increase in sympathetic activity could affect serving and receiving performance in volleyball[19]. It has also been confirmed that an increase in VLF% prior to competition could be a more sensitive parameter for sympathetic activity, as it is capable of detecting changes in the modulation of autonomic tone induced by precompetitive stress[19]. It may therefore be concluded that increased sympathetic activity, assessed by HRV, could negatively affect athletic performance[19]. Subjective variables are also used in a number of studies to supplement and/or link HRV-derived information. For example, RPE is used to monitor load[7,23,37], while several instruments are employed to monitor recovery in athletes, including wellness questionnaires[27,23], perceived recovery scales [39,7] and the DALDA questionnaire[37].

This systematic review has highlighted a number of limitations that must be taken into consideration when interpreting the results. Firstly, consideration should be given to the unique nature of elite sport and the complexity of recording HRV in team sports. The sample of specific studies on this type of sport is therefore small. Secondly, HRV is analysed on the basis of several variables, which makes it difficult to unify criteria when selecting studies for this review. There is a distinct lack of standardisation of HRV measures within the literature, which may lead to erroneous interpretations[18]. Thirdly, elite sport prioritises results, making it difficult to conduct recordings in a controlled and lengthier context. The duration and frequency of the measures vary greatly as a result of these practical restrictions. Lastly, the choice of device for recording HRV varies between studies and may have an impact on the consistency of the collected data.

In conclusion, HRV may be a valid tool for assessing adaptations to training load and monitoring recovery in athletes. RMSSD is the variable most commonly used to evaluate these adaptations. Although heart rate monitors are the most widely used devices for recording data in team sports, consideration is also given to other options such as ballistocardiography. Recording HRV values daily serves to identify changes in ANS activity. However, three recordings per week are sufficient for ensuring reliable results. Morning measurements in supine, standing and seated position are an effective method for assessing ANS activity. HRV is an individual marker, and each player displays different response patterns. As a result, the data must be interpreted at the individual level.

5. Conclusion

This systematic review demonstrates that HRV is a valuable tool for monitoring training adaptations, athlete readiness, recovery, and overall health in elite team sports. It offers a non-invasive, cost-effective method for assessing autonomic nervous system function, which is crucial for optimizing training regimens and preventing overtraining. There is a need for standardized protocols for HRV measurement to ensure consistency and reliability in data collection and interpretation, including consistent recording times, positions, and methods. HRV parameters should be interpreted on an individual basis due to the large variations in autonomic responses among athletes, allowing for personalized monitoring to enhance training and recovery programs tailored to each athlete's unique physiological profile. Continued research is necessary to refine HRV applications, establish best practices, and explore its full potential in elite team sports, including investigating the relationship between HRV and various performance outcomes and understanding the long-term benefits of HRV-guided training adjustments.

6. Practical applications

In the context of elite sport, the implementation of ultra-short-term HRV recordings could increase applicability. Establishing a recording protocol would help manage and adapt the training and recovery process to the needs of each athlete. Coaches play a key role in educating athletes and clearly explaining the purpose of HRV use. Showing how HRV can contribute to helping athletes meet their overall targets and improving their performance and match-day success may increase compliance in the long term. Adhering to the structure developed in this paper may assist practitioners in comprehending, analysing, and optimally utilizing HRV in team sports (See Fig. 2).

Abbreviations

ANS
Autonomic Nervous System
ECG
Electrocardiogram
HF
High Frequency
HRV
Heart Rate Variability
LF
Low Frequency
LnRMSSD
Natural Logarithm of RMSSD
PNS
Parasympathetic Nervous System
PROSPERO
International Prospective Register of Systematic Reviews
PRISMA

Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RMSSD
Root Mean Square of Successive Differences
RPE
Rate of Perceived Exertion
SDNN
Standard Deviation of NN intervals (normal-to-normal intervals)
SNS
Sympathetic Nervous System
TP
Total Power
ULF
Ultra-Low Frequency
VLF
Very Low Frequency

Declarations

Ethics Approval and Consent to Participate:

Not applicable. This study is a systematic review and did not involve human participants or animals.

Consent for Publication:

Not applicable. This study did not involve individual participants' data.

Availability of Data and Materials

The datasets generated and analysed during the current study are available from the corresponding author on reasonable request

Competing Interest:

The authors declare that they have no conflicts of interest.

Funding

This study was supported by the Spanish Government's Ministry of Science and Innovation (Ministerio de Ciencia e Innovación) under Grant Number: PID2019-107473RB-C21). The funders had no role in study design, data collection and analysis, decision to publish or preparation of the manuscript

Authors contribution

MO participated in the study collection, data selection, interpretation of the results, discussion and manuscript writing. LC participated in the study collection and manuscript translation. TC participated in the study collection and data selection and contributed to the interpretation of the results and discussion. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Acknowledgements

This work was supported by grants PID2019-107473RB-C21, funded by the Spanish Government (MCIN/AEI/10.13039/501100011033/FEDER, EU), and 2021SGR-00806, funded by the Government of Catalonia. The funders had no role in study design, data collection and analysis, decision to publish or preparation of the manuscript.

References

1. *Achten J, Jeukendrup AE.* Heart Rate Monitoring. Sports Medicine 2003; 33: 517–538

2. *Atlaoui D, Pichot V, Lacoste L, Barale F, Lacour J-R, Chatard J-C.* Heart Rate Variability, Training Variation and Performance in Elite Swimmers. Int J Sports Med 2007; 28: 394–400
3. *Bellenger CR, Miller D, Halson SL, Roach GD, Maclennan M, Sargent C.* Evaluating the Typical Day-to-Day Variability of WHOOP-Derived Heart Rate Variability in Olympic Water Polo Athletes. Sensors 2022; 22
4. *Blain G, Meste O, Bermon S.* Influences of breathing patterns on respiratory sinus arrhythmia in humans during exercise. American Journal of Physiology-Heart and Circulatory Physiology 2005; 288: H887–H895
5. *Borresen J, Ian Lambert M.* The Quantification of Training Load, the Training Response and the Effect on Performance. Sports Medicine 2009; 39: 779–795
6. *Bosquet L, Merkari S, Arvisais D, Aubert AE.* Is heart rate a convenient tool to monitor over-reaching? A systematic review of the literature. Br J Sports Med 2008; 42: 709–714
7. *Botonis PG, Smilios I, Toubekis AG.* Supercompensation in Elite Water Polo: Heart Rate Variability and Perceived Recovery. Sports Med Int Open 2021; 5: E53–E58
8. *Brandenberger G, Buchheit M, Ehrhart J, Simon C, Piquard F.* Is slow wave sleep an appropriate recording condition for heart rate variability analysis? Autonomic Neuroscience 2005; 121: 81–86
9. *Bricout V-A, DeChenaud S, Favre-Juvin A.* Analyses of heart rate variability in young soccer players: The effects of sport activity. Autonomic Neuroscience 2010; 154: 112–116
10. *Buchheit M.* Monitoring training status with HR measures: Do all roads lead to Rome? Front Physiol 2014; 5 FEB
11. *Buchheit M, Laursen PB, Ahmaidi S.* Parasympathetic reactivation after repeated sprint exercise. American Journal of Physiology-Heart and Circulatory Physiology 2007; 293: H133–H141
12. *Buchheit M, Mendez-Villanueva A.* Improbable effect of carbohydrate diet on cardiac autonomic modulation during exercise. Eur J Appl Physiol 2010; 109: 571–574
13. *Buchheit M, Simpson MB, Al Haddad H, Bourdon PC, Mendez-Villanueva A.* Monitoring changes in physical performance with heart rate measures in young soccer players. Eur J Appl Physiol 2012; 112: 711–723
14. *Burton NW, Pakenham KI, Brown WJ.* Feasibility and effectiveness of psychosocial resilience training: A pilot study of the program. Psychol Health Med 2010; 15: 266–277
15. *Capdevila L, Moreno J, Movellan J, Parrado E, Ramos-Castro J.* HRV based health&sport markers using video from the face. In: 2012 Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE, 2012: 5646–5649
16. *Capdevila Ortís L, Rodas Font G, Ocaña Mariné M, Parrado Romero E, Pintanel Bassets M, Valero Herreros M.* Variabilidad de la frecuencia cardíaca como indicador de salud en el deporte: validación con un cuestionario de calidad de vida (SF-12). Apunts Medicina de l'Esport 2008; 43: 62–69
17. *Cassirame J, Stuckey MI, Sheppard F, Tordi N.* Accuracy of the Minicardio system for heart rate variability analysis compared to ECG. J Sports Med Phys Fitness 2013; 53: 248–254
18. *Chrismas BCR, Taylor L, Thornton HR, Murray A, Stark G.* External training loads and smartphone-derived heart rate variability indicate readiness to train in elite soccer. Int J Perform Anal Sport 2019; 19: 143–152
19. *D'Ascenzi F, Alvino F, Natali BM, Cameli M, Palmitesta P, Boschetti G, Bonifazi M, Mondillo S.* Precompetitive assessment of heart rate variability in elite female athletes during play offs. Clin Physiol Funct Imaging 2014; 34: 230–236
20. *D'Ascenzi F, Alvino F, Natali BM, Cameli M, Palmitesta P, Boschetti G, Bonifazi M, Mondillo S.* Precompetitive assessment of heart rate variability in elite female athletes during play offs. Clin Physiol Funct Imaging 2014; 34: 230–236
21. *Esco MR, Flatt AA.* Ultra-short-term heart rate variability indexes at rest and post-exercise in athletes: evaluating the agreement with accepted recommendations. J Sports Sci Med 2014; 13: 535–541
22. *Flatt AA, Esco MR.* Evaluating Individual Training Adaptation With Smartphone-Derived Heart Rate Variability in a Collegiate Female Soccer Team. J Strength Cond Res 2016; 30: 378–385
23. *Flatt AA, Howells D.* Effects of varying training load on heart rate variability and running performance among an Olympic rugby sevens team. J Sci Med Sport 2018; 22: 222–226
24. *Friedrich D, Aubert XL, Führ H, Brauers A.* Heart rate estimation on a beat-to-beat basis via ballistocardiography - a hybrid approach. In: 2010 Annual International Conference of the IEEE Engineering in Medicine and Biology. IEEE, 2010: 4048–4051

25. *Gamelin F-X, Baquet G, Berthoin S, Thevenet D, Nourry C, Nottin S, Bosquet L.* Effect of high intensity intermittent training on heart rate variability in prepubescent children. Eur J Appl Physiol 2009; 105: 731–738
26. *Garet M, Tournaire N, Roche F, Laurent R, Lacour JR, Barthélémy JC, Pichot V.* Individual Interdependence between Nocturnal ANS Activity and Performance in Swimmers. Med Sci Sports Exerc 2004; 2112–2118
27. *Grainger A, Heffernan S, Waldron M, Sawczuk T.* Autonomic Nervous System Indices of Player Readiness During Elite-Level Rugby Union Game-Week Microcycles. J Strength Cond Res 2022; 36: 3173–3178
28. *Hautala A, Tulppo MP, Mäkikallio TH, Laukkanen R, Nissilä S, Huikuri H V.* Changes in cardiac autonomic regulation after prolonged maximal exercise. Clinical Physiology 2001; 21: 238–245
29. *Hemingway H, Shipley M, Brunner E, Britton A, Malik M, Marmot M.* Does Autonomic Function Link Social Position to Coronary Risk? Circulation 2005; 111: 3071–3077
30. *Holmes CJ, Sherman SR, Hornikel B, Cicone ZS, Wind SA, Esco MR.* Compliance of self-measured HRV using smartphone applications in collegiate athletes. Journal of High Technology Management Research 2020; 31
31. *Hynynen E, Uusitalo A, Konttinen N., Rusko H.* Heart Rate Variability during Night Sleep and after Awakening in Overtrained Athletes. Med Sci Sports Exerc 2006; 38: 313–317
32. *Lee CM, Wood RH, Welsch MA.* Influence of Short-Term Endurance Exercise Training on Heart Rate Variability. Med Sci Sports Exerc 2003; 35: 961–969
33. *Leti T, Bricout VA.* Interest of analyses of heart rate variability in the prevention of fatigue states in senior runners. Autonomic Neuroscience 2013; 173: 14–21
34. *Lewis P, Critchley H, Rotshtein P, Dolan R.* Neural Correlates of Processing Valence and Arousal in Affective Words. Cerebral Cortex 2006; 17: 742–748
35. *Malik M.* Heart Rate Variability. Annals of Noninvasive Electrocardiology 1996; 1: 151–181
36. *Mateo M, Blasco-Lafarga C, Martínez-Navarro I, Guzmán JF, Zabala M.* Heart rate variability and pre-competitive anxiety in BMX discipline. Eur J Appl Physiol 2012; 112: 113–123
37. *Milanez VF, Oliveira RS, De S, Ramos P, Leicht A.* The influence of a weekend of passive rest on the psychological and autonomic recovery in professional handball play. 2015 Available from: https://www.researchgate.net/publication/278677203
38. *Morales J, Álamo JM, García-Massó X, Buscà B, López JL, Serra-Añó P, González L-M.* Use of Heart Rate Variability in Monitoring Stress and Recovery in Judo Athletes. J Strength Cond Res 2014; 28: 1896–1905
39. *Moreno J, Ramos-Castro J, Rodas G, Tarragó JR, Capdevila L.* Individual recovery profiles in basketball players. Spanish Journal of Psychology 2015; 18
40. *Nakamura FY, Flatt AA, Pereira LA, Ramirez-Campillo R, Loturco I, Esco MR.* Ultra-Short-Term Heart Rate Variability is Sensitive to Training Effects in Team Sports Players. 2015 Available from: http://www.jssm.org
41. *Nakamura FY, Pereira LA, Esco MR, Flatt AA, Moraes JE, Abad CCC, Loturco I.* Intraday and interday reliability of ultra-short-term heart rate variability in rugby union players. 2016 Available from: www.nsca.com
42. *de Oliveira Ottone V, de Castro Magalhães F, de Paula F, Avelar NCP, Aguiar PF, da Matta Sampaio PF, Duarte TC, Costa KB, Araújo TL, Coimbra CC, Nakamura FY, Amorim FT, Rocha-Vieira E.* The Effect of Different Water Immersion Temperatures on Post-Exercise Parasympathetic Reactivation. PLoS One 2014; 9: e113730
43. *Otzenberger H, Gronfier C, Simon C, Charloux A, Ehrhart J, Piquard F, Brandenberger G.* Dynamic heart rate variability: a tool for exploring sympathovagal balance continuously during sleep in men. American Journal of Physiology-Heart and Circulatory Physiology 1998; 275: H946–H950
44. *Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE, Chou R, Glanville J, Grimshaw JM, Hróbjartsson A, Lalu MM, Li T, Loder EW, Mayo-Wilson E, McDonald S, McGuinness LA, Stewart LA, Thomas J, Tricco AC, Welch VA, Whiting P, Moher D.* The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. Syst Rev 2021; 10: 89
45. *Parrado E, Cervantes J, Pintanel M, Rodas G, Capdevila L.* Perceived Tiredness and Heart Rate Variability in Relation to Overload during a Field Hockey World Cup. Percept Mot Skills 2010; 110: 699–713
46. *Parrado E, García MÁ, Ramos J, Cervantes JC, Rodas G, Capdevila L.* Comparison of Omega Wave System and Polar S810i to Detect R-R Intervals at Rest. Int J Sports Med 2010; 31: 336–341

47. *Pichot V, Roche F, Gaspoz JM, Enjolras F, Antoniadis A, Minini P, Costes F, Busso T, Lacour JR, Barthélémy JC.* Relation between heart rate variability and training load in middle-distance runners. Med Sci Sports Exerc 2000; 32: 1729–1736
48. *Plews DJ, Laursen PB, Kilding AE, Buchheit M.* Evaluating Training Adaptation With Heart-Rate Measures: A Methodological Comparison. Int J Sports Physiol Perform 2013; 8: 688–691
49. *Plews DJ, Laursen PB, Meur Y Le, Hausswirth C, Kilding AE, Buchheit M.* Monitoring Training With Heart-Rate Variability: How Much Compliance Is Needed for Valid Assessment? Int J Sports Physiol Perform 2014; 9: 783–790
50. *Poh M-Z, McDuff DJ, Picard RW.* Non-contact, automated cardiac pulse measurements using video imaging and blind source separation. Opt Express 2010; 18: 10762
51. *Pumprla J, Howorka K, Groves D, Chester M, Nolan J.* Functional assessment of heart rate variability: physiological basis and practical applications. Int J Cardiol 2002; 84: 1–14
52. *Rajendra Acharya U, Paul Joseph K, Kannathal N, Lim CM, Suri JS.* Heart rate variability: a review. Med Biol Eng Comput 2006; 44: 1031–1051
53. *Ramos-Castro J, Capdevila Ortís L.* Variabilidad de la frecuencia cardíaca: concepto, medidas y relación con aspectos clínicos (I). 2008 Available from: https://www.researchgate.net/publication/46727114
54. *Ramos-Castro J, Moreno J, Miranda-Vidal H, Garcia-Gonzalez MA, Fernandez-Chimeno M, Rodas G, Capdevila L.* Heart rate variability analysis using a seismocardiogram signal. In: 2012 Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE, 2012: 5642–5645
55. *Ravé G, Zouhal H, Boullosa D, Doyle-Baker PK, Saeidi A, Abderrahman A Ben, Fortrat JO.* Heart Rate Variability is Correlated with Perceived Physical Fitness in Elite Soccer Players. J Hum Kinet 2020; 72: 141–150
56. *Rethlefsen ML, Kirtley S, Waffenschmidt S, Ayala AP, Moher D, Page MJ, Koffel JB, Blunt H, Brigham T, Chang S, Clark J, Conway A, Couban R, de Kock S, Farrah K, Fehrmann P, Foster M, Fowler SA, Glanville J, Harris E, Hoffecker L, Isojarvi J, Kaunelis D, Ket H, Levay P, Lyon J, McGowan J, Murad MH, Nicholson J, Pannabecker V, Paynter R, Pinotti R, Ross-White A, Sampson M, Shields T, Stevens A, Sutton A, Weinfurter E, Wright K, Young S.* PRISMA-S: an extension to the PRISMA Statement for Reporting Literature Searches in Systematic Reviews. Syst Rev 2021; 10: 39
57. *Rodas G, Pedret C, Ramos-Castro J, Capdevila Ortís L.* Variabilidad de la frecuencia cardiaca: conceptos, medidas y relación con aspectos clínicos (parte II). 2008 Available from: https://www.researchgate.net/publication/46727122
58. *Sandercock GRH, Brodie DA.* The use of heart rate variability measures to assess autonomic control during exercise. Scand J Med Sci Sports 2006; 16: 302–313
59. *Schmitt L, Regnard J, Desmarets M, Mauny F, Mourot L, Fouillot J-P, Coulmy N, Millet G.* Fatigue Shifts and Scatters Heart Rate Variability in Elite Endurance Athletes. PLoS One 2013; 8: e71588
60. *da Silva CC, Pereira LM, Cardoso JR, Moore JP, Nakamura FY.* The Effect of Physical Training on Heart Rate Variability in Healthy Children: A Systematic Review With Meta-Analysis. Pediatr Exerc Sci 2014; 26: 147–158
61. *Soares-Caldeira LF, de Souza EA, de Freitas VH, de Moraes SMF, Leicht AS, Nakamura FY.* Effects of Additional Repeated Sprint Training During Preseason on Performance, Heart Rate Variability, and Stress Symptoms in Futsal Players. J Strength Cond Res 2014; 28: 2815–2826
62. *Stanley J, Peake JM, Buchheit M.* Cardiac Parasympathetic Reactivation Following Exercise: Implications for Training Prescription. Sports Medicine 2013; 43: 1259–1277
63. *Thayer JF, Åhs F, Fredrikson M, Sollers JJ, Wager TD.* A meta-analysis of heart rate variability and neuroimaging studies: Implications for heart rate variability as a marker of stress and health. Neurosci Biobehav Rev 2012; 36: 747–756
64. *Thorpe RT, Atkinson G, Drust B, Gregson W.* Monitoring Fatigue Status in Elite Team-Sport Athletes: Implications for Practice. Int J Sports Physiol Perform 2017; 12: S2-27-S2-34
65. *Toufan M, Kazemi B, Akbarzadeh F, Amin A, Khalili M.* Assessment of electrocardiography, echocardiography, and heart rate variability in dynamic and static type athletes. Int J Gen Med 2012; 655
66. *Tulppo MP, Makikallio TH, Takala TE, Seppanen T, Huikuri H V.* Quantitative beat-to-beat analysis of heart rate dynamics during exercise. American Journal of Physiology-Heart and Circulatory Physiology 1996; 271: H244–H252
67. *Vesterinen V, Häkkinen K, Hynynen E, Mikkola J, Hokka L, Nummela A.* Heart rate variability in prediction of individual adaptation to endurance training in recreational endurance runners. Scand J Med Sci Sports 2013; 23: 171–180

Figures

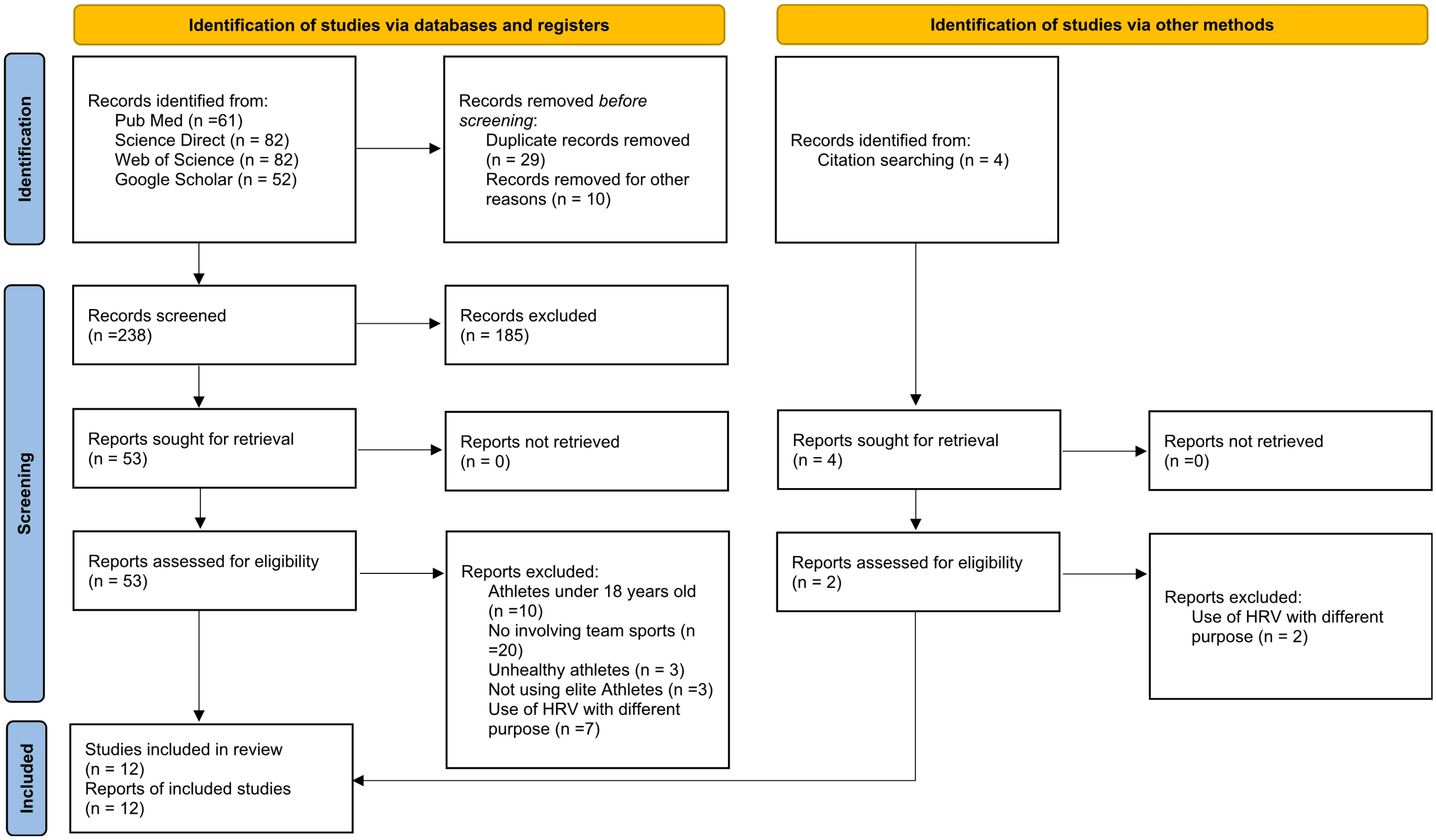

Figure 1

Article Selection Process. Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Systematic Reviews*, *10*(1), 89. https://doi.org/10.1186/s13643-021-01626-4

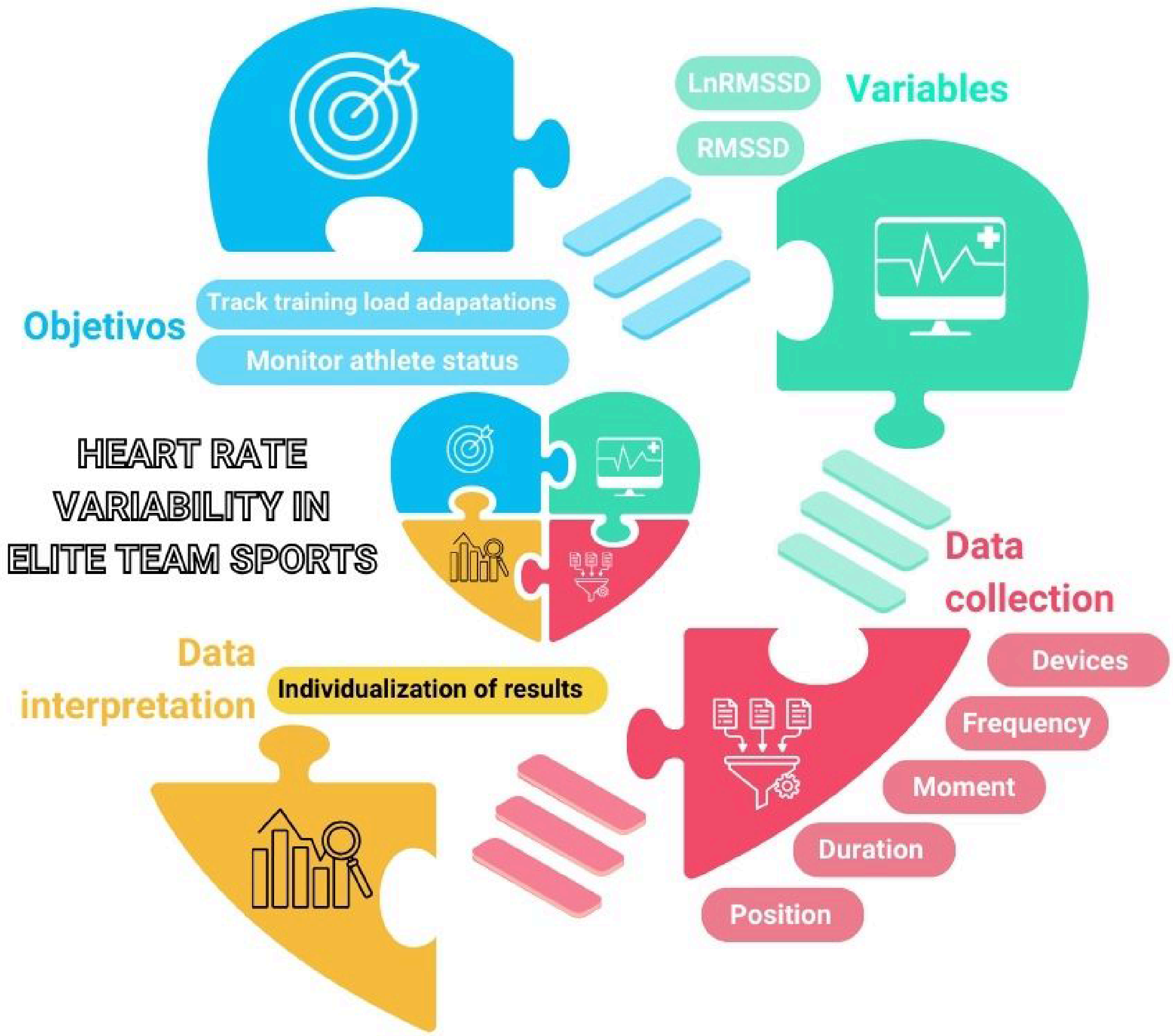

Figure 2

Legend not included with this version.