Received: 8 July 2022 | Revised: 12 May 2023 | Accepted: 16 May 2023

DOI: 10.1111/sms.14409

REVIEW

WILEY

Heart rate variability behavior in athletes after a sports concussion: A systematic review

Gonçalo Flores[1] | Diogo Monteiro[1,2,3] | Fernanda Silva[4] | Pedro Duarte-Mendes[5,6]

[1]ESECS—Polytechnic of Leiria, Leiria, Portugal

[2]Research Centre in Sport, Health and Human Development (CIDESD), Vila Real, Portugal

[3]Life Quality Research Center (CIEQV), Leiria, Portugal

[4]Research Unit for Sport and Physical Activity, University of Coimbra, Coimbra, Portugal

[5]Department of Sports and Well-being, Polytechnic Institute of Castelo Branco, Castelo Branco, Portugal

[6]Sport, Health and Exercise Research Unit—SHERU, Polytechnic Institute of Castelo Branco, Castelo Branco, Portugal

Correspondence
Pedro Duarte-Mendes, Department of Sports and Well-being, Polytechnic Institute of Castelo Branco, Castelo Branco, Portugal.
Email: pedromendes@ipcb.pt

Abstract

Objective: This systematic review aims to investigate the adaptations of the autonomic nervous system (ANS) after a concussion by measuring HRV in athletes over the age of 16 after injury.

Methods: This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA). Web of Science, Pubmed, SCOPUS, and Sport Discus were searched using predefined search terms to identify relevant original cross-sectional, longitudinal, and cohort epidemiological studies published before December 2021.

Results: After screening 1737 potential articles, four studies met the inclusion criteria. Studies included participants with concussion ($n=63$) and healthy control athletes ($n=140$) who practised different sports. Two studies describe a decrease in HRV following a sports concussion, and one proposed that the resolution of symptoms does not necessarily reflect ANS recovery. Lastly, one study concluded that submaximal exercise induces alteration in ANS, not seen in rest after an injury.

Conclusions: In the frequency domain, a decrease in high frequency power and an increase of low frequency/high frequency ratio is expected, as the activity of the sympathetic nervous system increases, and the parasympathetic nervous system decreases after injury. In the frequency domain, heart rate variability (HRV) may help monitor the activity of ANS evaluating signals of somatic tissue distress and early identification of other types of musculoskeletal injuries. Further research should investigate the relationship between HRV and other musculoskeletal injuries.

KEYWORDS

athlete (MeSH term), autonomic nervous system, sympathetic nervous system

1 | INTRODUCTION

The autonomic nervous system (ANS) links the central nervous system (CNS) with the rest of the body, primarily controlling the heart and the circulatory system through the cardiovascular control area and the higher brain centers in the brain stem.[1] The cardiovascular control area is characterized by the ability to adapt to physiological (e.g., pain) and/or environmental (e.g., horn) stimuli—to maintain cardiovascular homeostasis.[2] These adaptations depend on the interaction between the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS), two components of the ANS, which regulate the rate and variation of heartbeats through information from the baroreceptors.[2]

ANS activity in cardiac autonomic functions can be evaluated by the heart rate variability (HRV) analysis, which is defined as the variation in time between consecutive heartbeats, reflecting an interaction among the sympathetic and parasympathetic neural activity of the ANS.[2–5] Despite the influence of SNS and PNS in the HRV, this variable is also affected by other intrinsic factors, such as the reflex activity of baroreceptors, circulating hormones and local tissue metabolism, and extrinsic factors, such as environmental behavior.[1,4] HRV may be considered an indicator of health or disease since a reduction in HRV is associated with several risk factors like heart disease—including hypertension, diabetic neuropathy, and acute myocardial infarction.[6] In addition, it is also related to other health conditions such as diabetes and dyslipidemia.[3,6] On the contrary, individuals with high levels of HRV demonstrate greater performance in cognitive tasks such as concentration, working memory, and attention.[6,7]

HRV is measured by the intervals between consecutive heartbeats, visualized on the electrocardiogram as the R-R intervals between consecutive QRS complexes, and reflects the dynamic interaction from sympathetic and parasympathetic inputs of ANS.[7,8] HRV analysis includes time domain, frequency domain, or nonlinear analyses. The time domain, expressed in time units (milliseconds—ms), is based on R-R interval during a specific period and allows for calculation, through statistical methods, the standard deviation of R-R intervals (SDNN), the square root of the mean squared differences of successive R-R intervals (RMSSD), proportion derived by dividing R-R50 by the total number of R-R intervals (pNN50), among other measures.[2,7,8] In the frequency domain, HRV is decomposed through oscillatory components of the heart which allows the formation of a spectrum that divides oscillations into three main groups: very low frequencies (VLF; 0.0033–0.04 Hz), low frequencies (LF; 0.04–0.15 Hz), and high frequencies (HF; 0.15–0.4 Hz). LF reflects activity from the sympathetic and parasympathetic systems, with a predominance of sympathetic activity, and HF reflects the vagal tone and is used to assess parasympathetic cardiac tone.[2,6–8]

Sport is associated with a high rate of injuries due to the loads, repetitive movements, and contact injuries that occur during practice.[9] Overuse injuries are one of the main injuries observed in sports, related to numerous factors such as inadequate blood supply, muscle fatigue, or excessive loads.[9,10] The pathophysiological mechanisms are still uncertain, but it is known that an abnormal physiological response of the body leads to the development of numerous pathologies, such as tendinopathies, stress fractures, and hamstring ruptures.[10] Another frequent injury is the concussion—classified as a traumatic brain injury—caused by a blow to the head or body that results in pathophysiological alterations to the brain.[11] It reflects more of a functional disturbance than a structural injury, although several studies[11,12] show a relation between a musculoskeletal injury and a concussion. Furthermore, it is known that the pathomechanisms of concussion affect deeper brain regions as the severity of the injury increases.[4,6,13]

Thus, studies have demonstrated the influence of SNS and the PNS in response to injury, which induces the release of neuromediators through vagal afferents, which regulate pain, inflammation, and the healing process through baroreflex activity.[14] An imbalance between the SNS and the PNS may indicate a state of injury, leading to an increase in the sympathetic response and a decrease in parasympathetic activity.[1,10]

To the best of our knowledge, no other studies investigate HRV behavior after other types of musculoskeletal injuries, so in this systematic review, we focused on concussion since it was the only musculoskeletal injury assessed in the literature. Available data suggested that after a concussion, a reduction in HRV is observed during symptomatic phase,[15–18] and a reduction in HF power is observed after injury.[15,16,19,20] Although some studies observed a reduction in LF power,[15,16] Senthinathan et al.[19] demonstrate an increase in LF power. Moreover, the low frequency/high frequency (LF/HF) ratio presents high values during the first week after an injury that tends to decline.[19,20] Also, studies from Gall et al.,[16] and Senthinathan et al.,[19] showed the necessity to apply a physical load to detect ANS dysfunctions.

HRV is quantified as a marker of pathophysiological response, and it may be appropriate to investigate the ANS response after injury.[1,10] To the best of our knowledge, there is currently no systematic review and meta-analysis available that investigates the evidence regarding the associations between HRV and musculoskeletal injury. Therefore, this systematic review aims to analyze the adaptations of the ANS in a musculoskeletal injury obtained by measuring HRV in athletes up to 2 weeks after injury. We hypothesized that there is an alteration in HRV after a musculoskeletal injury.

2 | MATERIALS AND METHODS

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA).[21] The protocol has been registered at the PROSPERO International Prospective Register of Systematic Reviews under the registration number: CRD42021244529.

The search for this systematic review was conducted in the following databases: Web of Science, Pubmed, SCOPUS, and Sport Discus, accessed between March 1st, 2021 and August 20th, 2021. The search included all types of studies design and was limited to studies published in English. The search strategy combined Key Medical Subject Heading (MeSH) and search indexed descriptors to filter the data: ("heart rate variability" OR "HRV" OR "ANS") AND (sports [MeSH terms] OR exercise [MeSH terms]) AND (adult* [MeSH terms] OR "healthy adult" OR "young adult" [MeSH terms] OR athlete [MeSH terms]) AND (injury [MeSH terms]).

Studies included in this review meet the following criteria defined with the PICO[22] (Table 1): (1) studies that investigated the response of HRV in the frequency domain to musculoskeletal injury; (2) studies that evaluated HRV through electrocardiogram or other similar devices; (3) studies that reported data of individuals ≥16 years of age; (4) studies that reported healthy individuals without associated cardiac/respiratory (or other) complications; (5) cross-sectional, longitudinal, and cohort epidemiological studies; (6) peer-reviewed studies published in English. On the contrary, studies were excluded if the athlete was not evaluated within 2 weeks after injury.

The studies were imported to EndNote X9 software (Thompson Reuters, San Francisco, CA, USA), and duplicates were removed. The study selection procedure was performed in phases.[23] In the first phase, a search for studies relevant to the theme was carried out by two reviewers (GF and FS) based on the title and abstract. In the second phase, the preselected studies were reviewed by two independent reviewers (GF and FS) based on the eligibility criteria. In case of disagreement, the decision to include or not the study was resolved through a third reviewer (PM). The two reviewers involved in the selection of the studies independently participated in the extraction of data from the selected studies and the characteristics of the studies, including the name of the author, the country in which it was carried out, sample size, the methodological design, the type of sport performed by the athletes, the method obtained by HRV, and the type of injury in question. At this stage, discrepancies in the extracted data were resolved by consensus among reviewers (GF, FS, and PM).

The guidelines were followed based on the original PRISMA checklist, which describes the four stages (identification, screening, eligibility, and final selection) used for researching and selecting the most relevant articles.[21] A graphical flowchart design option was also performed. PRISMA presents the PICOS acronym (P—population; I—intervention; C—comparison; O—outcome; S—study design), which helped to define the research question and made systematic research more effective. The Newcastle-Ottawa Scale (NOS) was used by two investigators (GF and FS) to evaluate the quality and risk of bias of the 4-case control and cohort studies identified as eligible as recommended by the systematic review of Zeng et al.[24] The scores scale range is dependent on the study design.[25] The NOS questions vary from case–control to cohort studies.

TABLE 1 Search strategy and inclusion/exclusion criteria based on PICO strategy.

Search terms	PICO	Inclusion criteria	Exclusion criteria
Athletes Adult Young adult Healthy adult Sports Exercise	Population	Healthy athletes	Athletes with clinical conditions Nonathletes
Injury	Intervention	Musculoskeletal injury	Athletes with other complication (e.g., respiratory condition)
	Comparison	Injury athletes	Healthy athletes
Heart rate variability HRV ANS	Outcome	Heart rate variability in frequency domain (LF power, HF power, and LF/HF ratio)	Other variables of heart rate variability (e.g., time domain) Other methods to evaluate autonomic nervous system (photoplethysmography)

However, the quality score was calculated based on three similar variables—selection (4 points), comparability (2 points), and outcome (3 points)—for a total score of 9 points. A maximum of 1 point was awarded for each item in the selection and outcomes group, and a maximum of 2 points was awarded in comparability. According to NOS, the quality of articles was classified as "good quality" (scale 7–9), "fair quality" (scale 4–6), and "poor quality" (scale 0–3).[25] The degree of agreement (interrater reliability) between the two independent reviewers (G.F. and F.S.) was measured using Cohen's kappa (κ).

3 | RESULTS

The sequence followed for selecting the studies included in this systematic review is shown in Figure 1. The initial literature search identified a total of 1737 potentially eligible studies. After excluding studies based on duplicates (418), titles and abstracts (1290), 29 full-text articles were examined according to inclusion and exclusion criteria. After that, 25 studies were excluded for the reasons presented in Figure 1, and four studies remained for analysis.

Details of the four studies included in the systematic review are presented in Table 2. The four studies included participants with concussion (n = 63) and healthy control athletes (n = 140) who practised different sports (hockey, football, soccer, rugby, basketball, volleyball, lacrosse, and baseball). Studies from Hutchinson et al.[15] and Senthinathan et al.[19] included university athletes, Gall et al.[16] assessed Junior Hockey League athletes and Bishop et al.[5] evaluated athletes from Junior Hockey League and elite Hockey teams from National Hockey League and the American Hockey League. Bishop et al.[5] and Gall et al.[16] included only male participants, while the studies of Hutchinson et al.[15] and Senthinathan et al.[19] involved participants of both sexes. Two studies collected data sitting and standing from three similar moments: within the first week after injury, after the resolution of symptoms and 1 week after RTP. One study evaluated athletes at rest during an exercise protocol and collected data after injury (±48 h and 5 days later), after the resolution of symptoms and 5 days later. Finally, one study evaluated athletes during 10 s squats ±72 h after a concussion. The concussion was diagnosed by the physiotherapist or physician of the clubs in Bishop et al.,[5] Hutchinson et al.,[15] and Senthinathan et al.[19] and by the team trainers in Gall et al.[16] The study of Senthinathan et al.[19] used the Rivermead Concussion Questionnaire, Gall et al.[16] the concussion symptomatology outlined by the Canadian Hockey Association, Hutchinson et al.[15] the Sports Concussion Assessment Tool (SCAT 3) and Bishop et al.[5] the SCAT and the physiological measures for the diagnosed.

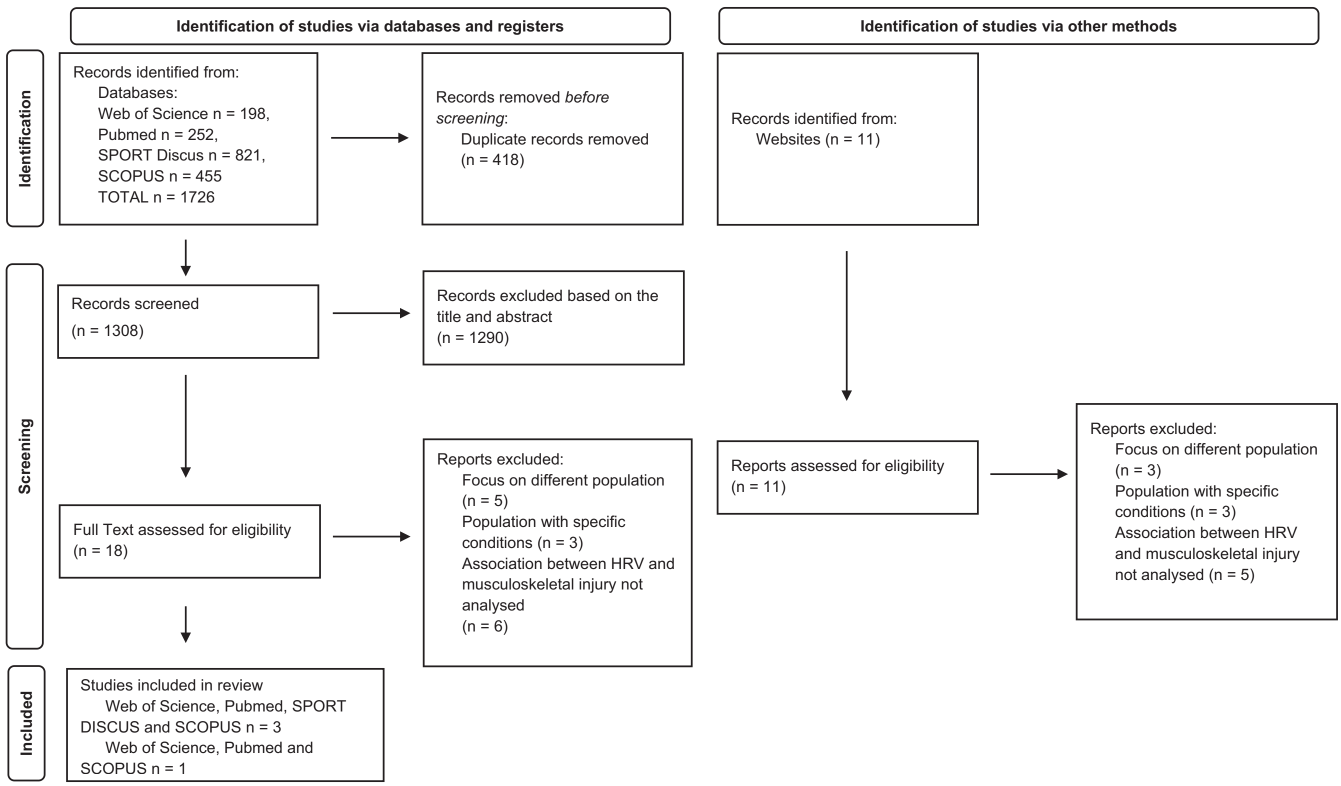

FIGURE 1 Search strategy flowchart. *From*: Page MJ et al. (2020).

Although all four studies assessed different components of HRV, the present systematic review focused on the frequency domain—specifically the low frequency power, high frequency power, and LF/HF ratio. Two studies measured HRV with an electrocardiogram (ECG) recording for at least 5 min, and the other used the Polar Heart Rate Monitor, following the guidelines of the European Society of Cardiology and the North American Society of Cardiology.[26] The frequency spectrum was divided into very low frequencies (0.0033–0.04 Hz), low frequencies (0.04–0.15), and high frequencies (0.15–0.4 Hz).

As mentioned, the NOS was used to evaluate the quality and risk of bias of the four eligible case–control and cohort studies. The NOS questions vary from case–control to cohort studies, and since this systematic review included three case–control studies and one cohort study, both versions were used. Table 3 shows the four studies included in this systematic review and meta-analysis: two studies had 8 points ("good quality"), and two had the maximum possible score (9/9). The kappa score for the identified cohort study was $\kappa = 0.639$ and for the case–control studies was $\kappa = 0.752$, showing a substantial level of agreement in the selected studies.[27]

Two studies describe a decrease in HRV following a sports concussion[5,15]; one associated this with an alteration in the vascular, myogenic tone, and vagal tone induced by sympathetic-baroreflex frequency alterations.[5] According to one study, the decrease in HRV after a concussion can depend on the sex and recovery milestones since the cardiac response to concussion differs in male and female athletes.[15] Another study also identified disturbances in ANS due to sports concussions and proposed that the resolution of symptoms does not necessarily reflect ANS recovery.[19] Another study concluded that submaximal exercise induces alteration in ANS after concussion that is not seen in rest.[16]

Besides that, some studies found HRV essential to evaluate the athlete after injury and allowed the identification and monitoring of the alteration in ANS throughout the recovery process.[15,16,19]

4 | DISCUSSION

This systematic review was developed to analyze the adaptations of the ANS after a concussion through HRV in the frequency domain. The extensive literature search reviewed publications for specific criteria, but studies on HRV in the frequency domain and musculoskeletal injury are scarce.

In the short-term period following a concussion, a reduction in HRV was observed in Hutchinson et al.[15] and Gall et al.[16] studies. This alteration was also observed by Hellard et al.[17] who evaluated athletes for 2 years and demonstrated HRV reduction before the symptomatic phase and during the symptomatic phase. These first adaptations from ANS resulted in alterations in brain function and structure. They were observed by McGee et al.,[28] Johnson et al.,[29] and Abaji et al.[20] The alterations observed in the frequency domain of HRV were detected during the first week after injury, after the resolution of symptoms and 1 week after return to play.[15] These findings were consistent with those of Gall et al.,[16] who detected the same pattern after the resolution of symptoms and 5 days later. These results are supported by Williams et al.,[18] who associate a decrease in HRV with the presence of markers of inflammation after injury. The HRV disturbances found by Hutchinson et al.[15] 1 week after RTP was also observed by Senthinathan et al.,[19] who concluded that the resolution of symptoms and the RTP do not necessarily indicate ANS recovery.

After a sports concussion, there is an imbalance between the SNS and PNS in response to the injury. Three studies from this systematic review demonstrate a reduction in HF power since there was a higher sympathetic activation and lower parasympathetic activation by ANS.[15,16,19] This is consistent with Abaji et al.,[20] who found the same results, although their study evaluates athletes in the postacute stage of injury. While all studies measured a higher sympathetic activation, Senthinathan et al.[19] refer to an increase in LF power in contrast to Gall et al.[16] and Hutchinson et al.,[15] both of which demonstrate a reduction in LF power.

Senthinathan et al.[19] and Abaji et al.[20] also demonstrate an LF/HF ratio with high values during the first week after the injury that tends to decline with time and recovery. The LF/HF ratio increase is associated with the withdrawal of parasympathetic activity,[20] as demonstrated by the decline of HF bands observed by Hutchinson et al.,[15] Senthinathan et al.,[19] and Gall et al.[16]

Although Bishop et al.[5] did not demonstrate changes between HRV at rest and during exercise, studies from Gall et al.,[16] and Senthinathan et al.,[19] showed that alterations in HRV are not detected at rest but suggested that a physical load like standing[19] or exercise[16] should be applied during HRV measurement to detect ANS dysfunctions. These findings agree with Abaji et al.[20] and La Fountaine et al.,[30] although this previous study does not evaluate HRV in the frequency domain. According to Gall et al.,[16] these alterations associated with exercise are due to "a disruption in the neuroanatomic pathway resulting in an uncoupling between the autonomic and cardiovascular system" (Gall et al.,[16]: page 1273). Although the mechanisms remain unclear, concussions result in cardiac autonomic dysfunction.[20]

The ANS is one of the primary systems activated after a concussion, regulating pain, inflammation, and

TABLE 2 Characteristics of included studies.

Author, Year, Country	Sample size (*n* total)	Age (years) (mean ± SD; range)	Study design	HRV assessment	Central outcomes	Main results	Main goals	Conclusions
Bishop et al. (2017)[5] Canada	101 males hockey players	17.78 ± 2.33 Control Group ($n = 89$) 19.92 ± 3.06 Intervention Group (n = 12)	Retrospective study	ECG system (Dual BioAmp, ADInstruments)	HRV: R-R mean ($p = 0.4$), R-R standard deviation ($p = 0.062$), average heart rate ($p = 0.71$), standard deviation of heart rate ($p = 0.056$), the number of intervals that differ by more than 50 milliseconds ($p < 0.05$), the percentage of NN50 relative to the sample ($p < 0.05$), very low frequency (p = 0.11), low frequency ($p = 0.15$), high frequency ($p = 0.12$), low frequency-high frequency ratio $p = 0.62$, % low frequency ($p = 0.87$), % high frequency ($p = 0.87$).	Statistical significance difference between healthy and concussed athletes in NN50 ($p = 0.033$) and pNN50 ($p = 0.012$).	To examine the baroreflex responses in the acute stage (within 72 h) of concussion in male athletes.	Heart rate standard deviations were significantly decreased statistically following concussion attributed to an altered vascular myogenic tone and/or an altered vagal tone.
Gall et al. (2004)[16] Canada	28 male hockey players	18.8 ± 0.4 control group ($n = 14$) 18.1 ± 0.4 Intervention Group ($n = 14$) (NA)	Longitudinal study	Burdick EK-10 Electrocardiograph and simultaneously a laptop using the WINDAQ® data acquisition system (US)	HRV: mean R-R interval ($p < 0.01$), standard deviation of R-R intervals ($p > 0.05$), low frequency power ($p < 0.05$), high frequency power ($p < 0.05$), total power ($p > 0.05$), and LF/HF ratio ($p > 0.05$).	Statistical significance in concussed athletes with a decrease in HF power, ($p > 0.05$), LF power ($p > 0.05$), and a decrease in average RR ($p > 0.01$) during low-moderate steady-state exercise bout compared to matched control.	To determine the neuroautonomic cardiovascular regulation in recently concussed athletes at rest and in response to low-moderate steady-state exercise.	Submaximal exercise induces a neuroautonomic cardiovascular dysfunction in concussed athletes not seen at rest. The damage associated with the concussion may be insufficient to induce neuroautonomic cardiovascular dysfunction at rest.
Hutchison et al. (2017)[15] Canada	52 (32 male and 20 female) Football; soccer; rugby; hockey; basketball; volleyball; lacrosse; baseball.	21 ± 2.5 control group ($n = 26$) and experimental group ($n = 26$) (18–28)	Case–control study	Polar Heart Rate Monitor and Polar Precision Performance Program Software, and Kubios HRV (Biosignal Analysis and Medical Imaging Group, Kuopio, Finland)	Physiological measures: HRV (mean R-R interval, standard deviation of R-R intervals, low frequency power, high frequency power, and total power) and salivary control Psychological measures: mood, perceived stress, and quality of sleep.	RR standard and HF were significantly between groups at any time ($p < 0.05$). LF shows significant differences at T2 ($p > 0.05$) and LF/HF increased pós-RTP ($p < 0.05$).	To evaluate psychological and physiological measures in concussed athletes.	The study confirms the resolution of mood disturbances and perceived stress by the time of medical clearance but identifies an autonomic nervous system disturbance in females across recovery and through RTP, manifested as depressed HRV.

TABLE 2 (Continued)

Author, Year, Country	Sample size (*n* total)	Age (years) (mean ± SD; range)	Study design	HRV assessment	Central outcomes	Main results	Main goals	Conclusions
Senthinathan et al. (2017)[19] Canada	22 (eight male and 14 females) Football (4); rugby (4); hockey (4); volleyball (2); lacrosse (4); basketball (2); soccer (2)	20.3 ± 0.6 control group ($n = 11$) 19.9 ± 0.8 Intervention Group ($n = 11$)	Prospective study	Polar Heart Rate Monitor and Polar Precision Performance Program Software and Kubios HRV (Biosignal Analysis and Medical Imaging Group, Kuopio, Finland)	HRV: Standard deviation of R-R intervals, average R-R interval, low frequency power, high frequency power, total power, LF/HF ratio, sample entropy, HF norm, and LF norm.	The concussion group shows significant decrease in entropy in all three phases ($p > 0.05$) and a decrease in LF power from phase 1 to phase 2 ($p = 0.02$). Also, concussion group shows significant decrease in HF norm at phase 1 while sitting.	To assess HRV in athletes with concussion in three phases: 1 week postinjury; during exercise progression; 1 week postmedical clearance to RTP.	Athletes with concussion displayed autonomic dysfunction in some measures of HRV after RTP. Also, resolution of symptoms do not necessarily reflect ANS recovery.

TABLE 3 Quality assessment scores of selected studies (Newcastle-Ottawa Scale).

	Selection				Comparability	Outcome			
Cohort Studies	Representativeness of the exposed cohort	Selection of the nonexposed cohort	Ascertainment of exposure	Demonstration that the current outcome of interest was not present at start of study	Comparability of cohorts on the basis of the design of analysis	Assessment of outcome	Was follow-up long enough for outcomes to occur	Adequacy of follow-up for cohorts	Quality scores
Bishop et al. (2017)[5]	X	X	X	X	XX	X	X	X	9/9
Case–control studies	Definition of cases	Representativeness of cases	Selection of controls	Definition of controls	Comparability of cases on the basis of the design of analysis	Assessment of exposure	Same method of ascertainment for cases and controls	Nonresponse rate	Quality scores
Gall et al. (2004)[16]	X	X	X	X	X	X	X	X	8/9
Hutchison et al. (2017)[15]	X	X	X	X	XX	X	X	X	9/9
Senthinathan et al. (2017)[19]	x	x	X	X	X	X	X	X	8/9

tissue repair via neuromodulators.[10,14] In fact, the ANS send efferent signals via the vagus nerve inhibiting pro-inflammatory cytokine via acetylcholine.[18] This system also influences the blood supply, transport of metabolic substances, and release of neuromediators involved in mechanotransduction.[10] After the injury, the inflammatory reflex is one of the primary responses, and a response from ANS is expected to initiate the inflammation process and healing process.[18]

This systematic review has tremendous methodological value due to the quality of the included studies. Although we tried to control the methodology as much as possible, this systematic review still presents some limitations. The heterogenicity of the protocols gives one limitation. More specifically, the time and number of evaluations and the valuation method since the studies included collecting data at rest, standing, and during submaximal exercise.

Another possible limitation could be the low number of enrolled patients between studies and the different instruments used to collect the HRV since two studies used an ECG, and the other two used a Polar Heart Rate Monitor. Also, all studies focus on concussions, and other musculoskeletal injuries, such as tendinopathy, are not explored. The restriction to only include studies that evaluated HRV in the frequency domain is likewise a limitation since the analyses in the time domain are a frequently validated method to evaluate heart rate variability. Finally, the option to include only studies published in English eliminates eligibility for studies written in other languages. Moreover, further research should be developed in this domain and different musculoskeletal injuries.

5 | CONCLUSION

This systematic review demonstrates the response of the ANS, though HRV, to concussion, confirming a decrease in HRV after injury. The dysfunctions induced by a physical load, not seen at rest, remain unclear, but the evaluation of HRV associated with a physical load seems to be more efficient.

Thus, the ANS plays a critical function in response to injury as it regulates the healing process of somatic tissue prior to pain or the full development of injury.[10] The data presented are highly relevant, allowing the use of HRV in the frequency domain to monitor the activity of ANS and could help clinical departments detect somatic tissue distress signals, allowing early identification of a concussion, reducing stop time, or facilitating a safer return to play.

6 | PERSPECTIVE

This systematic review demonstrates the response of the autonomic nervous system, though HRV, confirming a decrease in heart rate variability after injury. In the frequency domain, a decrease in high frequency power and an increase of low frequency/high frequency ratio is expected as the activity of sympathetic nervous system increased, and parasympathetic nervous system decrease. The data presented are extremely relevant, allowing the use of heart rate variability in the frequency domain to monitoring the activity of autonomic nervous system related to evaluated signals of somatic tissue distress and for the early identification of different types of musculoskeletal injuries.

FUNDING INFORMATION

No funding was received for this research.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

ORCID

Gonçalo Flores https://orcid.org/0000-0001-7672-4185
Diogo Monteiro https://orcid.org/0000-0002-7179-6814
Fernanda Silva https://orcid.org/0000-0001-8019-0729
Pedro Duarte-Mendes https://orcid.org/0000-0001-5055-2696

REFERENCES

1. Vitale JA, Bonato M, La Torre A, Banfi G. Heart rate variability in sports performance: Do time of day and chronotype play a role? *J Clin Med*. 2019;8(5):723.
2. Nakamura FY, Flatt AA. To vary or not to vary? Interpreting heart rate variability in soccer players. European Journal of. *Human Movement*. 2020;45:1-3.
3. Cilhoroz B, Giles D, Zaleski A, Taylor B, Fernhall B, Pescatello L. Validation of the Polar V800 heart rate monitor and comparison of artifact correction methods among adults with hypertension. *PLoS One*. 2020;15(10):e0240220.
4. Pereira LA, Flatt AA, Ramirez-Campillo R, Loturco I, Nakamura FY. Assessing shortened field-based heart-rate-variability-data acquisition in team-sport athletes. *Int J Sports Physiol Perform*. 2016;11(2):154-158.
5. Bishop S, Dech R, Baker T, Butz M, Aravinthan K, Neary JP. Parasympathetic baroreflexes and heart rate variability during acute stage of sport concussion recovery. *Brain Inj*. 2017;31(2):247-259.
6. Caminal P, Sola F, Gomis P, et al. Validity of the Polar V800 monitor for measuring heart rate variability in mountain running route conditions. *Eur J Appl Physiol*. 2018;118(3):669-677.
7. Conder RL, Conder AA. Heart rate variability interventions for concussion and rehabilitation. *Front Psychol*. 2014;5:890.

8. Forte G, Casagrande M. Heart rate variability and cognitive function: a systematic review. *Front Neurosci*. 2019;13:710.
9. Mugele H, Plummer A, Steffen K, Stoll J, Mayer F, Müller J. General versus sports-specific injury prevention programs in athletes: A systematic review 14 on the effect on injury rates. *PLoS One*. 2018;13(10):e0205635.
10. Gisselman AS, Baxter GD, Wright A, Hegedus E, Tumilty S. Musculoskeletal overuse injuries and heart rate variability: Is there a link? *Med Hypotheses*. 2016;87:1-7.
11. McPherson AL, Nagai T, Webster KE, Hewett TE. Musculoskeletal injury risk after sport-related concussion: a systematic review and meta-analysis. *Am J Sports Med*. 2019;47(7):1754-1762.
12. Herman DC, Zaremski JL, Vincent HK, Vincent KR. Effect of neurocognition and concussion on musculoskeletal injury risk. *Curr Sports Med Rep*. 2015;14(3):194-199.
13. Blake TA, McKay CD, Meeuwisse WH, Emery CA. The impact of concussion on cardiac autonomic function: a systematic review. *Brain Inj*. 2016;30(2):132-145.
14. Thayer JF, Åhs F, Fredrikson M, Sollers JJ III, 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(2):747-756.
15. Hutchison MG, Mainwaring L, Senthinathan A, Churchill N, Thomas S, Richards D. Psychological and physiological markers of stress in concussed athletes across recovery milestones. *J Head Trauma Rehabil*. 2017;32(3):E38-E48.
16. Gall B, Parkhouse WADE, Goodman D. Heart rate variability of recently concussed athletes at rest and exercise. *Med Sci Sports Exerc*. 2004;36:1269-1274.
17. Hellard P, Guimaraes F, Avalos M, Houel N, Hausswirth C, Toussaint JF. Modeling the association between HR variability and illness in elite swimmers. *Med Sci Sports Exerc*. 2011;43(6):1063-1070.
18. Williams DP, Koenig J, Carnevali L, et al. Heart rate variability and inflammation: a meta-analysis of human studies. *Brain Behav Immun*. 2019;80:219-226.
19. Senthinathan A, Mainwaring LM, Hutchison M. Heart rate variability of athletes across concussion recovery milestones: a preliminary study. *Clin J Sport Med*. 2017;27(3):288-295.
20. Abaji JP, Curnier D, Moore RD, Ellemberg D. Persisting effects of concussion on heart rate variability during physical exertion. *J Neurotrauma*. 2016;33(9):811-817.
21. Ardern CL, Büttner F, Andrade R, et al. Implementing the 27 PRISMA 2020 Statement items for systematic reviews in the sport and exercise medicine, musculoskeletal rehabilitation and sports science fields: the PERSiST (implementing Prisma in Exercise, Rehabilitation, Sport medicine and SporTs science) guidance. *Br J Sports Med*. 2022;56(4):175-195.
22. Methley AM, Campbell S, Chew-Graham C, McNally R, Cheraghi-Sohi S. PICO, PICOS and SPIDER: a comparison study of specificity and sensitivity in three search tools for qualitative systematic reviews. *BMC Health Serv Res*. 2014;14(1):1-10.
23. Silva F, Duarte-Mendes P, Rusennhack M, et al. Objectively measured sedentary behavior and physical fitness in adults: A systematic review and meta-analysis. *Int J Environ Res Public Health*. 2020;17(22):8660.
24. Zeng X, Zhang Y, Kwong JSW, et al. The methodological quality assessment tools for preclinical and clinical studies, systematic review and meta-analysis, and clinical practice guideline: a systematic review. *J Evid Based Med*. 2015;8(1):2-10.
25. Wells GA, Shea B, O'Connell D, et al. The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. *Appl Eng Agric*. 2014;18(6):727-734.
26. Camm AJ, Malik M, Bigger JT, et al. Heart rate variability: standards of measurement, physiological interpretation and clinical use Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. *Eur Heart J*. 1996;17(3):354-381.
27. McHugh ML. Interrater reliability: the kappa statistic. *Biochem Med*. 2012;22(3):276-282.
28. McCrea M, Prichep L, Powell MR, Chabot R, Barr WB. Acute effects and recovery after sport-related concussion: a neurocognitive and quantitative brain electrical activity study. *J Head Trauma Rehabil*. 2010;25(4):283-292.
29. Johnson B, Zhang K, Gay M, et al. Alteration of brain default network in subacute phase of injury in concussed individuals: resting-state fMRI study. *NeuroImage*. 2012;59(1):511-518.
30. La Fountaine MF, Heffernan KS, Gossett JD, Bauman WA, De Meersman RE. Transient suppression of heart rate complexity in concussed athletes. *Auton Neurosci*. 2009;148(1–2):101-103.

How to cite this article: Flores G, Monteiro D, Silva F, Duarte-Mendes P. Heart rate variability behavior in athletes after a sports concussion: A systematic review. *Scand J Med Sci Sports*. 2023;33:1598-1606. doi:10.1111/sms.14409