DOI: 10.1590/1809-2950/20022228032021

ORIGINAL RESEARCH

The use of heart rate variability analysis in monitoring sport injuries and its influence on the autonomic balance: a systematic review

O uso da análise da variabilidade da frequência cardíaca no monitoramento de lesões esportivas e sua influência sobre o balanço autonômico: uma revisão sistemática

El uso del análisis de variabilidad de la frecuencia cardíaca en el seguimiento de lesiones deportivas y su influencia en el balance autónomo: una revisión sistemática

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ABSTRACT | The objective of this review was to understand the use of heart rate variability (HRV) to identify its relationship with the occurrence of no contact sports injuries, in addition to indicating patterns of HRV after concussions and to the guidance in the process of returning to sport. A systematic review was carried out on the Pubmed, EMBASE, and PEDRo databases from its origin until December 2020, using the following terms: (((((athletes OR players) AND (Heart Hate Variability OR HRV)) AND (sport OR sports OR exercises OR physical activity)) AND (injuries OR injury)). The PICOS eligibility principles were: P (population): athletes, I (intervention): the use of HRV, C (control): uninjured athletes, O (outcomes): HRV indices and their relationship with sports injuries, and S (study): studies in humans. Of the 62 papers identified in the search, 12 were included in the review, 6 showing that decreased HRV and sympathetic-vagal imbalance are related to fatigue, overtraining, and overreaching; and 6 articles related to the assessment of HRV after a concussion, which identified changes in autonomic modulation in concussion athletes. In conclusion, the HRV may be a tool used in sports to identify a greater risk of no contact sports injuries, identifying situations of fatigue, overtraining, and overreaching, as well as assisting in the process of returning to sport after a cerebral concussion by assessing the autonomic balance.

Keywords | Sport; Wounds and Injuries; Heart Rate.

RESUMO | O objetivo desta revisão busca compreender o uso da variabilidade da frequência cardíaca (VFC) para identificar sua relação com a ocorrência de lesões esportivas que não envolvem contato, além de indicar padrões da VFC após concussões para orientar o retorno seguro ao esporte. Foi realizada uma revisão sistemática nas bases de dados *Pubmed, EMBASE* e *PEDRo,* incluindo artigos até dezembro de 2020, utilizando os seguintes termos: ((((*athletes OR players) AND (Heart Hate Variability OR HRV)) AND (sport OR sports OR exercises OR physical activity)) AND (injuries OR injury*)). Os princípios de elegibilidade de PICOS foram: P (*population*): atletas, I (*intervention*): o uso da VFC, C (*control*): atletas não lesionados, O (*outcomes)*: índices de VFC e suas relações com lesões esportivas, e S (*study*): estudos em seres humanos. De 62 artigos identificados na busca, 12 foram incluídos na revisão, sendo 6 mostrando que a diminuição da VFC e o desequilíbrio simpatovagal estão relacionados à fadiga, *overtraining* e *overreaching*; e 6 artigos relacionados com a avaliação da VFC pós-concussão, onde identificaram alteração de modulação autonômica nos atletas concussionados que vão além da ausência dos

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Corresponding address: Dr. Gustavo Dias Ferreira – R. Luís de Camões, 625-Pelotas (RS), Brasil – CEP: 96055-630 – E-mail: gustavo.ferreira@ufpel.edu.br – Financing source: nothing to declare – Conflict of interest: nothing to declare- Presentation: Jul. 30th 2021 - Accepted for publication: Aug. 21st 2021.

sintomas. Em conclusão, a VFC pode ser uma ferramenta utilizada no âmbito esportivo para identificar maior risco de lesões esportivas sem contato, identificando situações de fadiga, *overtraining* e *overreaching*, como também auxiliar no processo de retorno ao esporte pós-concussão cerebral pela avaliação do balanço autonômico.

Descritores | Esportes, Ferimentos e Lesões; Frequência Cardíaca.

RESUMEN | El objetivo de esta revisión fue estimar el uso de la variabilidad de la frecuencia cardíaca (VFC) para identificar su relación con la ocurrencia de lesiones deportivas sin contacto, así como indicar patrones de VFC después de concusiones para auxiliar en el regreso seguro al deporte. Se realizó una revisión sistemática en las bases de datos *PubMed, EMBASE* y *PEDRo* de artículos publicados hasta diciembre de 2020 utilizando las siguientes palabras clave: ((((*athletes OR players) AND (Heart Hate Variability OR HRV)) AND (sport OR sports OR exercises OR physical activity)) AND (injuries OR injury*)). Los principios de elegibilidad de PICOS fueron: P (*population*): atletas, I (*intervention*): el uso de VFC, C (*control*): deportistas sin lesión, O (*outcomes)*: índices de VFC y su relación con las lesiones deportivas, y S (*study*): estudios en humanos. De 62 artículos encontrados, se incluyeron 12 en la revisión, de los cuales 6 muestran que la disminución de la VFC y el desequilibrio simpatovagal están relacionados con la fatiga, *overtraining* y *overreaching*; y 6 artículos, con la evaluación de la VFC posconcusión, que identificaron cambios en la modulación autonómica en deportistas con conmoción que van más allá de la ausencia de síntomas. Se concluye que la VFC puede ser una herramienta útil para identificar un mayor riesgo de lesiones deportivas sin contacto como las situaciones de fatiga, *overtraining* y *overreaching*, así como para ayudar en el proceso de regreso al deporte después de una concusión cerebral mediante la evaluación del balance autonómico.

Palabras clave | Desportes; Lesiones; Heridas y Traumatismos; Frecuencia Cardíaca.

INTRODUCTION

The high performance sport requires levels of engagement of the athlete that approach the maximum in most of the season, making the professional overloaded, and this can often reach the psychological and physiological imbalance, potentiating the risk of developing injuries that harm their career[1]. In this way, finding a preventive approach, in search of reducing the chances of sports injuries, as well as monitoring the return of the athlete to their activity, can make this practice more efficient and safe[2-4].

Proper functioning of the cardiovascular system is essential for high-performance sports. Since the heart receives innervations from the autonomic nervous system (ANS), its control is according to the needs of our organism, varying its frequency of beats and ejected volume to supply the metabolic demand to maintain homeostasis[5]. Heart Rate Variability (HRV) has become an important biomarker of internal load in sport[4], for inferring the autonomic modulation of the human organism in a non-invasive way, with low cost and easy acquisition[4,6]. HRV describes the oscillations of the R-R intervals of the electrocardiogram, which are related to the autonomic influences on the sinoatrial node, and their indices can be obtained by means of linear methods, such as: by time, in the variable rMSSD (square root of the mean of the square of the differences between adjacent normal R-R intervals); or by high frequency (HF), indicator of the action of the vagus nerve on the heart, or low frequency (LF), resulting from joint action of the sympathetic and parasympathetic branch on HR. The LF/HF ratio expresses the autonomic balance[5,6].

Understanding, therefore, that analyzing HRV changes is also analyzing the behavior of the ANS, it is possible to use this tool in an attempt to monitor injuries, so common and inconvenient in sport[4]. A low HRV indicates that the ANS is not adapting sufficiently to the needs of the organism, which can suffer energy stress and fail[5]. Athletes with a predominance of sympathetic activation at rest tend to be more exposed to injuries or not yet ready to return to activity after an injury[6].

It is theorized that microtraumas accumulated in the somatic tissues of athletes can modulate the HRV response. Given this, it is understood that the abnormal inflammatory response of the tissue increases the modulation of the sympathetic nervous system and, consequently, changes the intervals between consecutive heartbeats, leading to an increase in metabolism even at rest[4,5]. Thus, it is assumed that HRV monitoring can provide useful information about the modulation of ANS in the human body and, in an athlete, changes in this system may reflect impacts on their training routine and performance.

Thus, this review aims to understand the use of HRV as a tool to predict increased risk of occurrence of non-contact sports injuries, and to describe recovery parameters for a safer return to sport.

METHODOLOGY

Design and search strategy

A systematic review was developed based on the indications of the Prisma Statement and AMSTAR2[7,8]. A search of articles in English was carried out in the databases PubMed, EMBASE and PEDRo, until December 2020. The Medical Subject Headings (MeSH) and its synonyms used were: ((((*athletes* OR *players*) AND (*Heart Hate Variability* OR *HRV*)) *and* (*sport or sports* OR *exercises* OR *physical activity*)) AND (*injuries* OR *injury*)).

Eligibility and selection criteria

According to the principles of peak eligibility, we consider P (population): the athletes, I (intervention): the use of HRV, C (control): non-injured athletes, O (outcomes): HRV indices and their relationships with sports injuries, and S (study): study in human beings.

The articles selected in the first search were evaluated by reading their titles and abstracts by three independent researchers (HGM, GCS, JGFS). In case of disagreement, a fourth author was called (GDF). After, readings of the complete article were performed to select and extract the data according to established criteria.

Study selection and data extraction

The inclusion criteria were articles on the use of HRV as a tool for predicting injuries or for monitoring athletes after the event to return to sport. It is important to note that, for Injury Risk Prediction variables, only non-contact musculoskeletal and joint injuries were included, as well as fatigue conditions and overtraining, since contact injuries are inherent to sports practice, they are less dependent on the athlete's anatomy and physiology, and cannot be detected by technological tools or prevented by health professionals. However, for post-injury follow-up, contact injuries were also added, since in this case the objective is to monitor the physiological recovery of the athlete after the damage. As exclusion criteria, articles in which HRV was not used as a physiological marker related to injuries, hypothesis studies or protocols without results were considered. For data extraction, the following were selected: author, year, country, type of study, participants, intervention, measures analyzed and main results.

RESULTS

Flow chart of studies

Our search identified 62 articles (52 in Pubmed, 8 in EMBASE and 2 in PEDro). After analysis of titles and abstracts 15 articles were selected for full evaluation. Out of these, 12 articles were included in the systematic review (Figure 1).

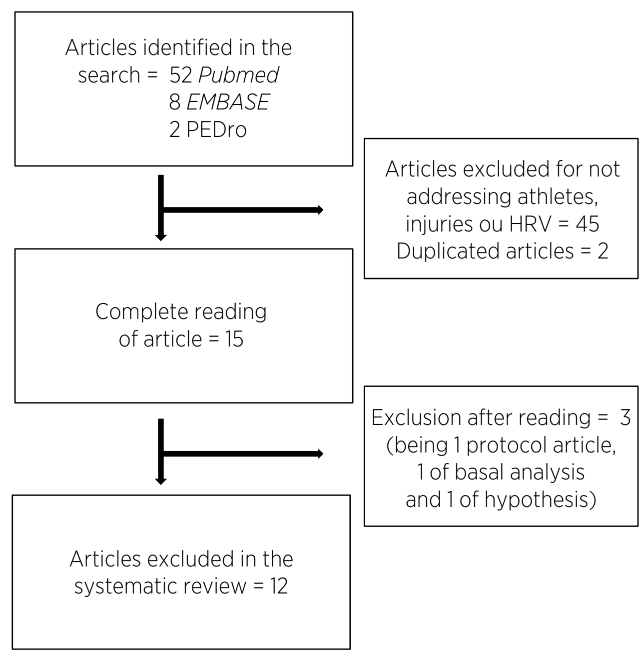

Figure 1. Flowchart of the studies: the search in the databases found 62 studies and, after selection, 12 were included in the systematic review

Description of studies

Tables 1 and 2 demonstrate the data extracted from the selected studies. Table 1 is an indication of the use of HRV to predict the increased risk of injury and its relationship with fatigue, overreaching and overtraining while Table 2 indicates the use of HRV to monitor parameters after injury, in which all included articles, coincidentally, treated concussion.

Table 1. Use of Heart Rate Variability (HRV) to predict increased risk of injury

Author, year and country	Type of study	Participants	Intervention	Measures analyzed	Main results
Lima-Borges 2018 Brazil	observational	Young athletes of the Brazilian national swimming team – Sprint: n=17 (13 men and 4 women) – Endurance: n=13 (7 men and 6 women)	Analysis of HRV at rest and competition, and its relationship to injury during a 20-week macrocycle	– HRV (rMSSD; LF; HF; LF/HF)	Athletes from sprint: decrease in HF and increase in LF, being related to episodes of overtrainning and injuries. Athletes from endurance: decrease in HRV, but with less effect than the group sprint.
Muñoz-López 2020 Spain	observational	23 professional soccer athletes – starters (trained and played more than 60 Minutes =11) – substitutes (only trained n=12)	HRV analysis during preparation for European competition comparing athletes exposed to high intensity games with substitutes.	– HRV (rMSSD);	More fatigued athletes, who performed in games for more than 60 minutes, remained with autonomic alteration (decrease in rMSSD) for up to 72 hours after the match, compared to the control reserves.
Williams 2017 United Kingdom	experimental	CrossFit ™ competitive athletes n=6 (3 men and 3 women)	Interaction between HRV, workloads and risk of overtrainning in a 16-week intervention	– HRV (rMSSD); – ACWR (acute/chronic workload ratio)	Increased risk of injury was related to low rMSSD index and high ACWR index. High loads were well tolerated when the rMSSD remained within the normality standard or was high.
Kajaia 2017 Georgia	observational	n=43 of athletes with overreaching non-functional and overtraining syndrome, n=40 athletes without these characteristics, n=35 sedentary	HRV analysis at rest	HRV at rest	Lower HRV, lower vagal influence and increased sympathetic stimulus during rest were observed in athletes with overreaching and overtraining.
Leti 2013 France	experimental	Senior long distance runner, mean age 51±5 years n=10	Night HRV monitoring over the 12-week period in rest, post-workout and post-competition conditions	– HRV (LF, HF, LF/HF) – Fatigue analysis questionnaire	Reduction of HF value and increase of LF and LF/HF after one day of competition. Positive correlations were found between fatigue and the LF frequency domain due mainly to the impact of competition.
Baumert 2006 Germany	experimental	Track and field and triathlon athletes n=10 (5 men and 5 women)	ECG monitoring for 2 weeks of field training with daily overload	– HRV at rest (rMSSD, LF and HF)	There was a reduction in HRV and vagal modulation during periods of intensified training.

n: sample number; HRV: Heart Rate Variability; rMSSD: mean square root of interval difference; LF: low frequency; HF: high frequency; ACWR: acute/chronic workload ratio; ECG: electrocardiogram.

Table 2: Use Of Heart Rate Variability to monitor parameters after concussion injury

Author, year and country	Type of study	Participants	Intervention	Measures analyzed	Main results
Paniccia 2018; Canada	longitudinal	Adolescent sportsmen from 13 to 18 years followed, from the diagnosis of concussion	Use of HRV with 24-hour monitoring log	– HRV	Parasympathetic modulation drop until Day 30 post-injury, combining with physical, cognitive, emotional and fatigue symptoms. An increase in parasympathetic modulation was observed up to day 90, with minimal symptoms. There was a return to the stability of parasympathetic modulation around 120 days

(continues)

Table 2: Continuation

Author, year and country	Type of study	Participants	Intervention	Measures analyzed	Main results
Johnson 2018 USA	experimental	College athletes with concussion and symptomatic n=11 (5 women and 6 men) and Healthy college athletes n=10 (5 women and 5 men).	Evaluation of HRV during the Face Cooling	– FC; -R-R Interval; – rMSSD; – HF	In post-concussion patients, HR and R-R interval do not change in the first minutes of Face Cooling, unlike healthy ones that increase the parasympathetic response.
Hutchison 2017 Canada	Case-control	College athletes: n=52 (32 men and 20 women): 26 with concussion and 26 healthy as control group.	Analysis in three recovery periods: – Between 2 and 7 days post-injury (symptomatic period) – At the beginning of the progression of the exercise – 1 week after return to training	Psychological aspects: – Mood – Sleep quality – Perceived stress Physiological aspects: – HRV	Psychological aspects were worse in athletes with concussion in the symptomatic phase. In athletes with concussion there is a reduction in HF during the three periods analyzed, indicating that an autonomic dysregulation may remain even after return to training, especially in women.
Senthinathan 2017 Canada	experimental	Athletes diagnosed with concussion n=11, and undiagnosed athletes, as a control group n=11	Analysis in three recovery periods: symptomatic phase, asymptomatic phase, and 1 week after the return to training with the evaluation protocol in the sitting and standing position.	Domain variables frequency and time of HRV in athletes of the sitting and standing protocol.	Athletes with concussion presented in the symptomatic phase increased LF and decreased HF. During the phase of return to training, they presented higher LF/HF when sitting. When moving from sitting to standing position, athletes presented autonomic changes in all phases when compared to control.
Abaji 2016 Canada	transversal	n=12 male athletes with concussion and n=12 control athletes	HRV analysis measured at rest and during isometric hand holding practice	– HRV: (R-R interval, rMSSD, LF, HF, LF/HF)	Asymptomatic athletes with concussion, in the post-acute stage of injury (95 days±63), still present a reduced parasympathetic modulation and higher LF/HF ratio during isometric hand grip test.
Gall 2004 Canada	experimental	=14 hockey athletes with concussion and n=14 control athletes.	Evaluation of HRV at rest and during moderate intensity exercise session on the second and seventh day after injury.	– HRV: (R-R interval, LF, HF, LF/HF)	At rest, no changes were noticed. During exercise, athletes with concussion demonstrated a reduction in the mean of the R-R intervals, and a change in the powers of LF and HF, which indicates that there was no sympathovagal modulation in response to exercise.

n: sample number; HRV: Heart Rate Variability; HR: heart rate; rMSSD: mean square root of interval difference; LF: low frequency; HF: high frequency; R-R: interval between two R waves of the electrocardiogram.

DISCUSSION

In this review, we addressed the use of HRV to assist in the process of predicting non-contact injuries, and for returning to sports after a concussion.

Regarding the increased risk of non-contact injuries, athletes of higher intensities, with training and competitions of high loads and repetitiveness, are exposed to a great sympathetic activation during most of the macrocycle, even during rest, and are more frequent targets of overtraining, which increases the chance of injury, compared to athletes of less intense trials[6]. In a similar way it happens with football professionals exposed to high intensity matches, where there is a decrease in autonomic modulation of more fatigued athletes for up to 72 hours after the match[9].

In the same sense, there is an increased risk of injury when athletes presented low rMSSD (low HRV) and high training load (ACWR – acute / chronic workload ratio), also highlighting that injuries are more frequent in those athletes with high LF/HF and who, nevertheless, train intensively (high ACWR), influencing the process of capacity/demand[10].

Fatigue caused by training and competitions is directly related to a higher sympathetic tone, in addition, a more satisfactory recovery is related to a predominance of parasympathetic tone during rest. In runners, the main imbalance of the ANS, with a sympathetic predominance at rest, occurs the day after a competition, due to physical impact and psychological stress[11].

Greater sympathetic cardiac modulation is observed due to increased frequency and intensity of stimuli, which can lead athletes to present a state of overreaching[12], physiological change by excessive training related to an autonomic imbalance and, consequently, a change in HRV[13].

It is also important to emphasize that the conditions considered so far are not those generated by physical contact, because in these there are no physiological markers that allow the prediction of the injury, since it is the result of external impact and not physiological changes.

We observed, in the studies presented, that excessive sympathetic modulation is often associated with excessive or intense training (overtraining, overreaching), states of fatigue and short recovery period, situations that normally increase the risks of injuries. Therefore, it is clear that HRV can be a valuable tool to provide useful information to minimize injuries in sport, by monitoring the autonomic balance of athletes, so that there is professional intervention to adjust the training load and recovery time of the athlete to their physiological capabilities.

As HRV can be a valuable tool to aid in predicting injuries, it can also be an important method for tracking athletes after injuries, such as concussions. This is because athletes with concussion have a low adaptability of ANS, and as long as they do not resume these responses to physiological levels, they will be at risk if they return to their activities[14]. The study of Johnson and collaborators carried out the technique of Face Cooling (application of ice at 0ºC on the face of the athletes) and did not observe expected and adaptive responses of the ANS in the variables of HRV in athletes who had had a concussion, demonstrating deficit of internal control[15].

In the study by Hutchison et al., athletes who suffered concussions had parasympathetic dysregulation (decreased HF) that extended from the post-injury period to one week after returning to training, when the athletes no longer had symptoms[16]. Athletes with concussion already asymptomatic, in the post-acute stage of the injury (on average 95 days after), still presented a reduced parasympathetic modulation, indicated by the reduction of the absolute value of HF in response to a strength test[17].

It is also added that the higher the number of concussions already suffered by athletes, the higher the LF/HF at rest, even after returning to sport, clarifying the greater recurrence and possibility of being affected by this type of injury again[18].

Within the framework of the analysis of recovery after concussion, HRV can be divided into 3 phases. The first of these consists in the increase of sympathetic modulation until about the 30th day after the injury with great manifestation of symptoms (physical, cognitive, emotional and fatigue). In the second phase, there is an increase in parasympathetic modulation until about the 75th day post-concussion for the male sex and 90th day for the female sex, in which there is a decrease in symptoms. The third phase goes up to, on average, the 120th day for the male sex which is when normally no more symptoms are presented and there is an autonomic balance, and in women this aspect may take even longer[19]. The change in parameters of female athletes was more sensitive after concussion, hypothesizing parasympathetic dysregulation (lower HF and higher risk of injury). Men, on the other hand, tend to be more sensitive to sympathetic dysregulation, which explains male athletes having greater post-concussion mood disorders[16].

In practice, the return to sport happens long before the autonomic balance, which can leave the athlete at risk of having a new injury or concussion. The studies reported return to training dependent on symptoms presented, with medians of 14 and 18 days post-concussion, however, with a very high amplitude[16,18]. Although athletes often minimize symptoms, concussions can cause metabolic damage that persists for a longer period[16], which can be accompanied by the use of HRV evaluation, suggesting readiness and avoiding early return. This was demonstrated when athletes with concussion presented disturbances in HRV in the sitting and standing position, both in the symptomatic and asymptomatic phases, indicating that athletes released to train, even if they are asymptomatic, may still present metabolic dysregulation and are not completely recovered, requiring a more individualized follow-up[18].

Finally, the study of Gall, Parkhouse and Goodman[20], evaluated HRV in the acute post-concussion period, and observed that although at rest there were no differences between a group of athletes who had concussion compared to a control group, during exercise (bicycle), post-concussion athletes demonstrated a reduction in the mean of the R-R intervals, and change in the powers of LF and HF, which indicates a poor sympathovagal modulation in response to exercise.

Strengths and limitations of the review

The main limitation of this work was the selection of articles only from the English language, however, it is justified by this topic being specific and relatively new, so the intention was to include articles published in journals with greater impact and visibility to compose the review. Another limitation point was that, even with this systematized selection, the articles included in the review did not report the use of methods of blinding the sample and the researchers, who had access to the athletes' training, competition and injury history. However, this work has as a positive aspect that the articles included describe data from HRV assessments prior to injuries, to assist in the risk profile and identify whether the athlete is more or less exposed to non-contact injuries; as well as analysis of HRV in the post-concussion recovery period, to enable decision-making by health professionals regarding the return to sport with greater safety.

CONCLUSION

HRV can be a tool used in sports to identify higher risk of non-contact sports injuries, identifying that low variability or autonomic imbalance are related to fatigue situations, overtraining and overreaching, as well as assisting in the process of returning to sports post-concussion by assessing the athlete's readiness. Thus, we encourage the use of HRV as a tool to be used by the health team in sports.

REFERENCES

1. Terra VDS, Falcoski F, Padovani RC, Colantonio E. A meditação no esporte de alto rendimento: revisão sistematizada da literatura. Pensar Prat. 2018;21(2):459-77. doi: 10.5216/rpp.v21i2.48561.
2. Lauersen JB, Bertelsen DM, Andersen LB. The effectiveness of exercise interventions to prevent sports injuries: a systematic review and meta-analysis of randomised controlled trials. Br J Sports Med. 2014;48(11):871-7. doi:10.1136/bjsports-2013-092538.
3. van Mechelen W, Hlobil H, Kemper HC. Incidence, severity, aetiology and prevention of sports injuries. A review of concepts. Sports Med. 1992;14(2):82-99. doi:10.2165/00007256-199214020-00002.
4. Gisselman AS, Baxter GD, Wright A, Hegedus E, Tumilty E. Musculoskeletal overuse injuries and heart rate variability: is there a link? Med Hypotheses. 2016; 87:1-7. doi: 10.1016/j.mehy.2015.12.003
5. Vanderlei LC, Pastre CM, Hoshi RA, Carvalho TD, Godoy MF. Basic notions of heart rate variability and its clinical applicability. Rev Bras Cir Cardiovasc. 2009;24(2):205-17. doi:10.1590/s0102-76382009000200018.
6. Lima-Borges DS, Martinez PF, Vanderlei LCM, Barbosa FSS, Oliveira-Junior SA. Autonomic modulations of heart rate variability are associated with sports injury incidence in sprint swimmers. Phys Sportsmed. 2018;46(3):374-384. doi:10.1080/00913847.2018.1450606.
7. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gotzsche PC, Ioannidis JP, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. J Clin Epidemiol. 2009;62(10):e1-34. doi: 10.1016/j.jclinepi.2009.06.006.
8. Shea BJ, Reeves BC, Wells G, Thuku M, Hamel C, Moran J, et al. AMSTAR 2: a critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both. BMJ. 2017;358:j400. doi: 10.1136/bmj.j4008.
9. Muñoz-López A, Nakamura F, Orellana JN. Soccer matches but not training sessions disturb cardiac-autonomic regulation during national soccer team training camps. Res Q Exerc Sport. 2021;92(1):43-51. doi: 10.1080/02701367.2019.1708843.
10. Williams S, Booton T, Watson M, Rowland D, Altini M. Heart rate variability is a moderating factor in the workload-injury relationship of competitive CrossFit™ athletes. J Sports Sci Med [Internet]. 2017 [cited 2021 Sep 27];16(4):443-9. Available from: https://bit.ly/39KyrF8
11. Leti T, Bricout VA. Interest of analyses of heart rate variability in the prevention of fatigue states in senior runners. Auton Neurosci. 2013;173(1-2):14-21. doi:10.1016/j.autneu.2012.10.007.
12. Baumert M, Brechtel L, Lock J, Hermsdorf M, Wolff R, Baier V, et al. Heart rate variability, blood pressure variability, and baroreflex sensitivity in overtrained athletes. Clin J Sport Med. 2006;16(5):412-7. doi:10.1097/01.jsm.0000244610.34594.07.
13. Kajaia T, Maskhulia L, Chelidze K, Akhalkatsi V, Kakhabrishvili Z. The effects of non-functional overreaching and overtraining on autonomic nervous system function in highly trained athletes. Georgian Med News. 2017;(264):97-103.
14. Bishop SA, Dech RT, Guzik P, Neary JP. Heart Rate Variability and implication for sport concussion. Clin Physiol Funct Imaging. 2018; 38(5):733-42. doi: 10.1111/cpf.12487.
15. Johnson BD, O'Leary MC, McBryde M, Sackett JR, Schlader ZJ, Leddy JJ. Face cooling exposes cardiac parasympathetic and sympathetic dysfunction in recently concussed college athletes. Physiol Rep. 2018;6(9):e13694. doi:10.14814/phy2.13694.
16. 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. doi:10.1097/HTR.0000000000000252.
17. Abaji JP, Curnier D, Moore RD, Ellemberg D. Persisting effects of concussion on Heart Rate Variability during physical exertion. J Neurotrauma. 2016;33(9):811-7. doi:10.1089/neu.2015.3989.

18. 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):288-95. doi:10.1097/JSM.0000000000000337.

19. Paniccia M, Taha T, Keightley M, Thomas S, Verweel L, Murphy J, et al. Autonomic function following concussion in youth athletes: an exploration of heart rate variability using 24-hour recording methodology. J Vis Exp. 2018;(139):58203. doi:10.3791/58203.

20. Gall B, Parkhouse W, Goodman D. Heart rate variability of recently concussed athletes at rest and exercise. Med Sci Sports Exerc. 2004;36(8):1269-74. doi:10.1249/01.mss.0000135787.73757.4d.