Heart rate variability in musculoskeletal injuries: a tool to monitoring early signs of somatic tissue distress in soccer athletes

Master's Thesis

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ABSTRACT

Heart rate variability is defined as the variation in time between consecutive heartbeats and reflects the dynamic interaction between the sympathetic and parasympathetic nervous system, two branches of autonomic nervous system. The autonomic nervous system regulates the healing process after a musculoskeletal injury through the activation of the efferent vagal fibers who increase blood supply, transport of metabolic substances and the release of proinflammatory cytokines. The use of heart rate variability for the early identification of a non-traumatic musculoskeletal injury or to enable a safer return-to-play must be investigated. Therefore, in this work, we initially conduct a systematic review to understand the adaptations of the autonomic nervous system to a musculoskeletal injury through the measurement of heart rate variability in athletes. We conclude that in frequency domain, a decrease in high frequency power and in low frequency power, as well as an increase in low frequency/high frequency ratio is expected after injury. Subsequently and informed by the results found in the systematic review, we performed a longitudinal study to analyse the adaptations of the autonomic nervous system after a musculoskeletal injury by measuring heart rate variability in athletes in the acute phase of injury and after the return-to-play. Results show a reduction in low frequency power and low frequency/high frequency ratio, and an increase in high frequency power after injury. The differences between the two studies could be explained be the different types of pathologies, since studies included in the systematic review focused only on concussion and the longitudinal study presents additional types of musculoskeletal injuries. Further investigation should be developed that considers a wide range of musculoskeletal injuries and sports modalities.

Keywords

Athlete, autonomic nervous system, heart rate variability, sympathetic nervous system.

RESUMO

A variabilidade da frequência cardíaca é definida como a variação no tempo entre batimentos cardíacos consecutivos e reflete a interação dinâmica entre o sistema nervoso simpático e o sistema nervoso parassimpático, dois ramos do sistema nervoso autónomo. O sistema nervoso autónomo regula o processo de cura após uma lesão musculoesquelética através da ativação das fibras vagais eferentes responsáveis pelo aumento do suprimento sanguíneo, do transporte de substâncias metabólicas e da libertação de citocinas pró-inflamatórias. A utilização da variabilidade da frequência cardíaca para a identificação precoce de uma lesão musculoesquelética não traumática ou para um retorno ao desporto mais seguro deve ser investigada. Assim, neste trabalho, realizámos inicialmente uma revisão sistemática para perceber as adaptações do sistema nervoso autónomo na lesão musculoesquelética através da medição da variabilidade da frequência cardíaca em atletas. Concluímos que no domínio da frequência, uma diminuição das bandas de baixa e de alta frequência, assim como uma diminuição do rácio é expectável após uma lesão. Posteriormente e com base nos resultados da revisão sistemática, desenvolvemos um estudo longitudinal para analisar as adaptações do sistema nervoso autónomo após uma lesão musculoesquelética, através da medição da variabilidade da frequência cardíaca em atletas na fase aguda da lesão e após o regresso à competição. Os resultados demonstraram uma redução nas bandas de baixa frequência e no rácio, e um aumento nas bandas de altas frequências após a lesão. Os diferentes resultados entre estudos podem ser explicados pelos diferentes tipos de patologias, uma vez que os estudos incluídos na revisão sistemática referem apenas a concussão e o estudo longitudinal apresenta outros tipos de lesões musculoesqueléticas. Mais investigação deve ser desenvolvida considerando um maior

espectro de lesões musculoesqueléticas e diferentes tipos de modalidades.

Palavras-chave

Atletas, variabilidade da frequência cardíaca, sistema nervoso autónomo, sistema nervoso simpático.

List of Publications

The present thesis is comprised of the following papers:

- **Flores, G.**, Monteiro, D., Silva, F., Duarte-Mendes, P. (Under Review in *Scandinavian Journal of Medicine and Science in Sports*). Heart rate variability behaviour after injury: a systematic review.

- **Flores, G.**, Monteiro, D., Silva, F., Duarte-Mendes, P. (Under Review in *Journal of Sports Sciences*). Heart rate variability activity in soccer athletes after a musculoskeletal injury.

ORAL COMMUNICATIONS

The first study of this thesis was presented in the following congresses:

- **Heart rate variability behaviour in athletes after injury: a protocol for a systematic review and meta-analysis** presented in XXII Jornadas da Sociedade Portuguesa de Psicologia do Desporto, held at Department of Human Motricity and Artistic Languages from School of Education and Social Sciences, Polytechnic of Leiria and the Portuguese Society of Sport Psychology, on November 4th – 6th, 2021 (Appendix 1).

- **Heart rate variability behaviour in athletes after injury: a systematic review** presented in EUCAPA 2022 – European Congress of Adapted Physical Activity, held at the University of Coimbra, Faculty of Sport Sciences and Physical Education, Portugal, on June 9th - 11th, 2022. Abstract published in *European Journal of Adapted Physical Activity* 2022, 15(6), 33 (doi: 10.5507/euj.2022.003) (Appendix 2).

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ABBREVIATIONS

ANS - Autonomic Nervous System

ECG - Electrocardiogram

HF - High Frequency

HRV - Heart Rate Variability

κ - Cohen's Kappa

LF - Low Frequency

LF/HF ratio - Low Frequency/High Frequency Ratio

ms - milliseconds

η2 – Eta Square Value

NOS - Newcastle-Ottawa Scale

n.u. - Normalized Units

pNN50 - Proportion Derived by Dividing R-R50 by the Total Number of R-R Intervals

PNS - Parasympathetic Nervous System

PRISMA - Preferred Reporting Items for Systematic Reviews and Meta-analysis

RMSSD - Square Root of the Mean Squared Differences of Successive R-R Intervals

RTP - Return-to-Play

SDNN - Standard Deviation of R-R Intervals

SNS - Sympathetic Nervous System

VLF - Very Low Frequency

INTRODUCTION

The present thesis was developed under the scope of the master's degree in Exercise Prescription and Health Promotion, of the School of Education and Social Sciences, Polytechnic of Leiria. The main body of this work is divided in two parts, namely: Chapter 1 - Heart rate variability behaviour in athletes after injury: a systematic review; and Chapter 2 – Heart rate variability activity in soccer athletes after a musculoskeletal injury.

The autonomic nervous system plays an important role after a musculoskeletal injury regulating the healing process, and his activity can be evaluated through heart rate variability. Thus, heart rate variability can be used to evaluate early signs of somatic tissue distress or to facilitate a safer return-to-play in athletes. There is currently no systematic review and meta-analysis available that investigates the association between heart rate variability and musculoskeletal injury, so the purpose of Chapter 1 is to present a systematic review who analyse the adaptations of the autonomic nervous system in a musculoskeletal injury, obtained by measuring heart rate variability in athletes, up to two weeks after injury.

In Chapter 2 and based on the results found in the systematic review, we develop a longitudinal study to analyse the adaptations of the autonomic nervous system after a musculoskeletal injury by measuring heart rate variability in athletes in the acute phase of injury and after the return-to-play. This study was conducted in three soccer clubs in the central region of Portugal and heart rate variability was collected using the polar m200 and a polar heart rate monitor chest strap H10 (Polar Electro Oy, Kempele, Finland).

Chapter 1 – Heart rate variability behaviour in athletes after injury: a systematic review

Abstract

The aim of this systematic review is to investigate the adaptations of the autonomic nervous system (ANS) after a musculoskeletal injury obtained by measuring heart rate variability (HRV) in young and adult athletes after injury. 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 studies, published until August 2021. After screening 1737 potential articles, four studies met the inclusion criteria. Studies included participants with concussion (n= 63) and healthy control (n= 140), who practiced different sports. Two studies describe a decreased in HRV following a sport-concussion, and one proposed that resolution of symptoms does not necessarily reflects ANS recovery. Lastly, one study concluded that submaximal exercise induces alteration in ANS, not seen in rest, after injury. In the frequency domain, a decrease in low frequency power and in high frequency power, as well as an increase of low frequency/high frequency ratio was observed, as the activity of sympathetic nervous system increase, and parasympathetic nervous system activity decrease after injury. HRV may be useful for monitoring the activity of ANS evaluating signals of somatic tissue distress, and early identification of other types of injuries. Further research should be performed to investigate the relationship between HRV and others musculoskeletal injuries.

Keywords: autonomic nervous system, musculoskeletal disease (MeSh term), sports (MeSH term), sympathetic nervous system.

INTRODUCTION

The autonomic nervous system (ANS) links the central nervous system with the rest of the body, primarily controlling the heart and the circulatory system through the cardiovascular control area and the higher brain centers located in the brainstem (Speer at al., 2020; Vitale et al., 2019; Dong, 2016). 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 (Voss et al., 2015). 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 (Voss et al., 2015; Koenig et al., 2014; da Silva et al., 2015; Cilhoroz et al., 2020).

ANS activity in cardiac autonomic functions can be evaluated by the analysis of heart rate variability (HRV) which is defined as the variation in time between consecutive heartbeats, reflecting an interaction among sympathetic and parasympathetic neural activity of the ANS (Giles et al., 2016; Pereira et al., 2016; Bishop et al., 2017; Caminal et al., 2018; Voss et al., 2015). Despite the influence of SNS and PNS in the HRV, this component is also affected by other intrinsic factors, such as the reflex activity of baroreceptors, circulating hormones and local tissue metabolism, and by extrinsic factors such as environmental behaviour (Bishop et al., 2017; Vitale et al., 2019). HRV may be considered as an indicator of health or disease, since a reduction in HRV is associated with several risk factors like heart diseases - including hypertension, diabetic neuropathy and acute myocardial infarction (Conder & Conder, 2014). In addition, it is also related to other health conditions such as diabetes and dyslipidemia (Conder & Conder, 2014; Giles et al., 2016; Dong, 2016). On the other hand, individuals with high levels of HRV demonstrate greater performance in cognitive tasks such as concentration, working memory and attention (Forte et al., 2019; Conder & Conder, 2014).

HRV is measured by the intervals between consecutive heartbeats, visualized on the electrocardiogram as the R-R intervals between consecutive QRS complexes, and reflect the dynamic interaction from sympathetic and parasympathetic inputs of ANS (Forte et al., 2019; Raffin et al., 2019). HRV analysis includes time domain, frequency domain or non-linear analyses. The time domain, expressed in time units (milliseconds – ms), is based on R-R intervals 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 (Forte et al., 2019; Voss et al., 2015; Raffin et al., 2019; Nakamura et al., 2020). In the frequency domain, HRV is decomposed through oscillatory components of the heart which allows the formation of a spectrum that divides oscillations in 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 sympathetic and parasympathetic system, with a predominance of sympathetic activity, and HF reflect the vagal tone and is used to assess parasympathetic cardiac tone (Forte et al., 2019; Voss et al., 2015; Conder & Conder, 2014; Raffin et al., 2019).

Sports are associated with a high rate of injuries due to the loads, repetitive movements and contact injuries that occur during practice (Mugele et al., 2018; Kisser & Bauer, 2012). Overuse injuries are one of the main injuries observed in sports, being related to numerous factors such as inadequate blood supply, muscle fatigue or excessive loads (Gisselman et al., 2016; Mugele et al., 2018). The pathophysiological mechanisms are still uncertain, but it is known that there is an abnormal physiological response of the body that leads to the development of numerous pathologies such as tendinopathies, stress fractures and hamstring ruptures (Gisselman et al., 2016). Another frequent injury is the concussion - classified as a traumatic brain injury - that is caused by a blow in the head that results in pathophysiological alterations to the brain (McPherson et al., 2019). It reflects more of a functional disturbance instead of a structural injury, although studies from Herman et al. (2015) and McPherson et al. (2019) shows a relation between a musculoskeletal injury and a concussion. Furthermore, it is known that the pathomechanics of concussion affects deeper brain regions as the severity of the injury increases (Blake et al., 2016; Bishop et al., 2017; Conder & Conder, 2014)

Thus, studies have demonstrated the influence of SNS and the PNS in response to injury, which induce the release of neuromediators through vagal efferent, who regulate pain, inflammation and the healing process through baroreflex activity (Thayer et al., 2012; Chuang et al., 2007). 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 (Gisselman et al., 2016; Vitale et al., 2019; Koenig et al., 2014).

Available data suggested that after a concussion, a reduction in HRV is observed during symptomatic phase (Hutchinson et al., 2017; Gall et al., 2004; Hellard et al., 2011; Williams et al., 2019) and a reduction in HF power is observed after injury (Hutchinson et al., 2017; Senthinathan et al., 2017; Gall et al., 2004; Abaji et al., 2016). Even though some studies observed a reduction in LF power (Gall et al., 2004; Hutchinson et al., 2017), Senthinathan et al. (2017) demonstrate an increase in LF power. Moreover, the low frequency/high frequency ratio (LF/HF ratio) presents high values during the first week after injury that tends to decline (Senthinathan et al., 2017; Abaji et al., 2016). Also, studies from Gall et al. (2004) and Senthinathan et al. (2017) 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 (Dong, 2016; Vitale et al., 2019; Koenig et al., 2014; Gisselman et al., 2016). 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, the aim of this systematic review is to analyse the adaptations of the ANS in a musculoskeletal injury, obtained by measuring HRV in athletes, up to two weeks after injury. We hypothesized that there is an alteration in HRV after a musculoskeletal injury.

MATERIAL AND METHODS

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) (Ardern et al., 2022; Page et al., 2021). The protocol has been registered at the PROSPERO International Prospective Register of Systematic Reviews under the registration number: CRD42021244529.

Data Sources

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 the 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]).

Eligibility Criteria and Selection of Studies

Studies included in this review, meet the following criteria defined with the PICO (Methley et al., 2014) (Table 1): (1) studies that investigated the response of HRV in 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) peer-reviewed studies published in English. On the other hand, studies were excluded if the athletes were not evaluated within 2 weeks after injury.

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 - Non-athletes
- 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 methods of heart rate variability assessment (e.g., time domain) - Other methods to evaluate autonomic nervous system activity (photoplethysmography)

DATA EXTRACTION

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 (Silva et al., 2020; Ferraz et al., 2020). In the first phase, a search for studies relevant to the theme was carried out by two reviewers (GF, FS) based on the title and abstract. In the second phase, the pre-selected studies were reviewed by two independent reviewers (GF, 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 age of the athletes, the country in which it was carried out, sample size, the methodological design, the type of sport performed by the athletes, the method used to obtain HRV, the central outcomes, the main results and goals, and the principal conclusions were collected. At this stage, discrepancies about the extracted data were resolved by consensus among reviewers (GF, FS, PM).

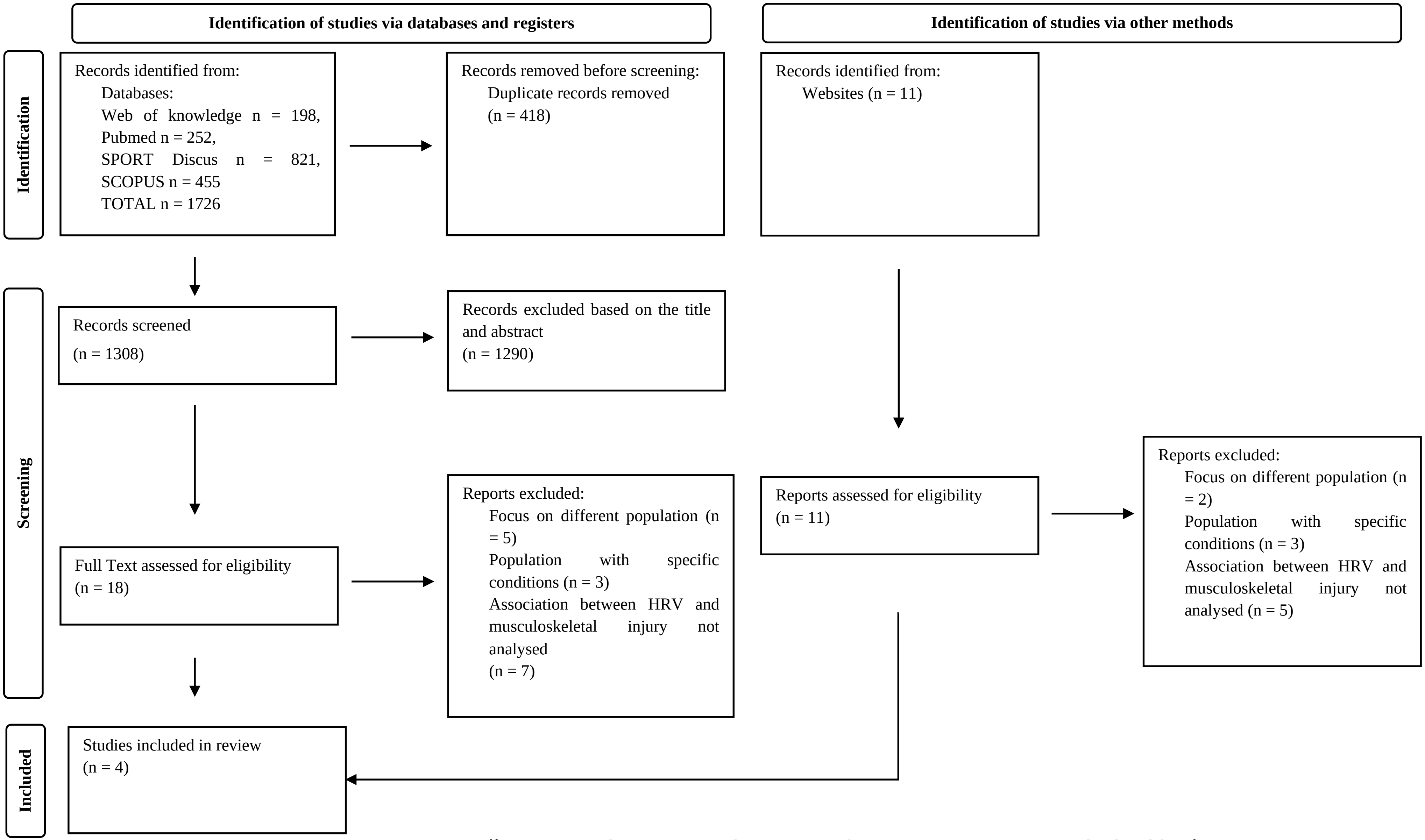
Quality Assessment

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 suitable articles (Ardern et al., 2022; Page et al., 2021). A graphical flowchart design option was also performed. PRISMA presents the PICOS acronym (P - population; I - intervention; C - comparison; O - results; S - study design), which helped to define the research question and makes systematic research more effective. The Newcastle-Ottawa Scale (NOS) was used by two investigators (GF, FS) to evaluate the quality and risk of bias of the three case control studies and the cohort study, identified as eligible, as recommended by the systematic review of Zeng et al. (2015). The scores scale range are dependent on the study design (Wells et al., 2014). The NOS questions vary from case control to cohort studies, but 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 selection and outcomes group and a maximum of 2 points was awarded in comparability. According to NOS, a higher score represents better methodological quality (Wells et al., 2014). The degree of agreement (interrater reliability) between the two independent reviewers (GF and FS) was measured using Cohen's kappa (κ).

RESULTS

DATA SEARCH

The sequence followed for the selection of the studies that were 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, remaining 4 studies for analysis.



Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., & Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *International Journal of Surgery*, 88, 105906. doi: 10.1136/bmj.n71. For more information, visit: http://www.prisma-statement.org/

Figure 1. Search strategy flow chart.

Characteristics of Studies

The four studies included participants with concussion (n= 63) and healthy control (n= 140), who practiced different sports (hockey, football, soccer, rugby, basketball, volleyball lacrosse and baseball). Bishop et al. (2017) and Gall et al. (2004) included only male participants, while the studies of Hutchinson et al. (2017) and Senthinathan et al. (2017) involved participants of both sexes. Two studies collected data sitting and standing from three similar moments: within the first week after injury, after resolution of symptoms and 1 week after return-to-play (RTP). One study assessed athletes at rest, during an exercise protocol and collected data after injury (± 48h and 5 days later), after resolution of symptoms and five days later. Finally, one study evaluated athletes during 10s squats ±72h after concussion.

Despite all four studies assessed different components of HRV, the present systematic review focuses on the frequency domain - more specifically the LF power, HF power, and LF/HF ratio. Two studies measure HRV with an electrocardiogram (ECG) recording at least 5 minutes and the other two used the polar heart rate monitor, following the guidelines of the European Society of Cardiology and the North American Society of Cardiology (Camm et al., 1996). The frequency spectrum was divided in VLF (0.0033 – 0.04 Hz), LF (0.04 – 0.15) and HF (0.15 – 0.4 Hz).

Risk of Bias in Studies

As mentioned before, 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 1 cohort study, both versions were used. Table 2 shows the four studies included in this systematic review: 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 $\kappa=0.639$ ($p < 0.001$) and for the case control studies was $\kappa=0.752$ ($p < 0.001$), showing a substantial level of agreement in the different types of studies selected (McHugh, 2012).

Table 2. Quality assessment scores of selected studies (Newcastle-Ottawa Scale).

	Selection				Comparability	Outcome			
Cohort Studies	**Representativeness of the exposed cohort**	**Selection of the non-exposed 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)	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**	**Non response rate**	**Quality scores**
Gall et al. (2004)	x	x	x	x	x	x	x	x	8/9
Hutchison et al. (2017)	x	x	x	x	xx	x	x	x	9/9
Senthinathan et al. (2017)	x	x	x	x	x	x	x	x	8/9

SYNTHESIS OF RESULTS

Details of the four studies included in the systematic review are presented in Table 3. Bishop et al. (2017) and Hutchinson et al. (2017) describe a decreased in HRV following a sport-concussion, one associated this to an alteration in the vascular myogenic tone and/or in the vagal tone (Bishop et al., 2017). According to Hutchinson et al. (2017), the decrease in HRV after concussion can depend on the sex and recovery milestones. Senthinathan et al. (2017) also identified disturbances in ANS due to sport concussion and proposed that resolution of symptoms do not necessarily reflects ANS recovery. Gall et al. (2004) concluded that submaximal exercise induces alteration in ANS after concussion that is not seen in rest.

Thus, some studies consider HRV as an important indicator to identify and monitoring the alterations in ANS after injury and throughout the recovery process (Gall et al., 2004; Hutchinson et al., 2017; Senthinathan et al., 2017).

Table 3. Characteristics of included studies.

Author, Year, Country	Sample Size (n total), Type of sport	Age (years) (mean ± SD)	Study Design	HRV assessment	Central outcomes	Main Results	Main Goals	Conclusions
Bishop et al. (2017) Canada	101 males Hockey Players	17.78 ± 2.33 Control Group (n= 89) 19,92 ± 3.06 Intervention Group (n= 12)	Retrospective cohort 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 hours) 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) Canada	28 Male Hockey Players	18,8 ± 0,4 Control Group (n= 14) 18,1 ± 0,4 Intervention Group (n=14)	Case control 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 low frequency/high frequency ratio ($p > 0.05$).	Statistical significance in concussed athletes with a decrease in high frequency power, ($p > 0.05$), low frequency 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) **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)	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 high frequency were significantly between groups at any time ($p < 0.05$). low frequency shows significant differences at T2 (p > 0.05) and low frequency/high frequency ratio 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.

Senthinathan et al. **(2017)** **Canada**	22 (8 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 case control 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, low frequency/high frequency ratio, sample entropy, high frequency norm and low frequency norm.	The concussion group shows significant decrease in entropy in all three phases (*p* > 0.05) and a decrease in low frequency power from phase 1 to phase 2 (*p* = 0.02). Also, concussion group shows significant decrease in high frequency norm at phase 1 while sitting.	To assess HRV in athletes with concussion in three phases: 1 week post injury; 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 does not necessarily reflect ANS recovery.

DISCUSSION

This systematic review was developed to analyse the adaptations of the ANS after a concussion, through HRV in frequency domain. Throughout the extensive literature search, publications were reviewed under specified criteria, but studies on HRV in frequency domain and musculoskeletal injury are scarce.

In the short-term period after a concussion, a reduction in HRV was observed in Hutchinson et al. (2017) and Gall et al. (2004) studies. This alteration was also observed in Hellard et al. (2011) who evaluated athletes for two years and demonstrate HRV reduction before the symptomatic phase and during the symptomatic phase. This first adaptations from ANS results in alterations in brain function and structure and were observed by McCrea et al. (2010), Johnson et al. (2012) and Abaji et al. (2016). The alterations observed in frequency domain of HRV was detected during the first week after injury, after resolution of symptoms and one week after return to play (Hutchinson et al., 2017), and consistent with findings by Gall et al. (2004) who detected the same pattern after resolution of symptoms and five days later. These findings are supported by Williams et al. (2019) who associate a decreased in HRV with the presence of markers of inflammation, presented after injury. The HRV disturbances founded by Hutchinson et al. (2017) one week after RTP were also observed by Senthinathan et al. (2017) who concluded that 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 in all times since there was a higher sympathetic activation and lower parasympathetic activation by ANS (Hutchison et al., 2017; Senthinathan et al., 2017; Gall et al., 2004), which is consistent with Abaji et al. (2016) who found the same results although their study evaluates athletes in the post-acute stage of injury. Even though all studies considered a higher sympathetic activation, Gall et al. (2004) and Hutchinson et al. (2017) demonstrate a reduction in LF power.

Senthinathan et al. (2017) and Abaji et al. (2016) also demonstrate a LF/HF ratio with high values during the first week after injury that tends to decline with time and recovery. The increase in LF/HF ratio are associated with the withdrawal of parasympathetic activity (Abaji et al., 2016), as demonstrated by the decline of HF power observed in studies from Hutchinson et al. (2017), Senthinathan et al. (2017) and Gall et al. (2004).

Although Bishop et al. (2017) did not demonstrate changes between HRV at rest and during exercise, studies from Gall et al. (2004) and Senthinathan et al. (2017) showed that alterations in HRV are not detected at rest but suggested that a physical load like standing (Senthinathan et al., 2017) or exercise (Gall et al., 2004) should be applied during HRV measurement to detect ANS dysfunctions. These findings agree with Abaji et al. (2016) and La Fountaine et al. (2009), although this last study does not evaluate HRV in frequency domain. According to Gall et al. (2004), 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., 2004: page 1273).

The ANS is one of the primary systems activated after injury, regulating pain, inflammation and tissue repair via neuromodulators (Gisselmann et al., 2016; Thayer et al., 2012; Chuang et al., 2007). In fact, the ANS send efferent signals releasing pro-inflammatory cytokine via acetylcholine (Williams et al., 2019). This system also influences the blood supply, transport of metabolic substances and release of neuromediators involved in mechanotransduction (Gisselman et al., 2016; Koenig et al., 2014). After injury the inflammatory reflex is one of the primary responses and is an expected response from ANS to initiate the inflammation process and healing process (Williams et al., 2019).

This systematic review has a high methodological value due to the quality of the included studies. However, although we have tried to control the methodology as much as possible, this systematic review presents some limitations. One limitation is given by the heterogenicity of the protocols more specifically the time and number of evaluations, and the valuation method since the studies included collect data at rest, standing and during submaximal exercise. Another possible limitation could be linked to the different instruments used to collect HRV, since two studies used an ECG and the other two, a Polar Heart Rate Monitor. Also, all studies focus on concussion, and other types of musculoskeletal injuries as tendinopathy, for example, are not explore. Finally, the option to include only studies published in English, eliminates eligible studies written in other languages. We should be aware that further research should be developed in frequency domain and in different types of musculoskeletal injuries.

CONCLUSION

This systematic review demonstrates the response of the ANS, though HRV, to concussion, confirming a decrease in HRV after injury. In the frequency domain, a decrease in HF power and in LF power, as well as an increase of LF/HF ratio is expected as the activity of SNS increased and PNS decrease. The disfunctions 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 an important function in response to injury as it regulates the healing process of somatic tissue prior even to pain or full development of injury (Gisselman et al., 2016). The data presented are extremely relevant, allowing the use of HRV in the frequency domain to monitor the activity of ANS related to evaluated signals of somatic tissue distress and for the early identification of other types of musculoskeletal injuries.

Chapter 2 – Heart rate variability activity in soccer athletes after a musculoskeletal injury

Abstract

The aim of this study is to analyse the adaptations of the autonomic nervous system (ANS) after a musculoskeletal injury, obtained by measuring heart rate variability (HRV) in athletes in acute phase and after the return-to-play (RTP). 15 male soccer players, aged between 21 and 33, with a recent musculoskeletal injury were selected. HRV was collected using the Polar m200 and a polar heart rate monitor chest strap H10 (Polar Electro Oy, Kempele, Finland) in two different moments, within 72h after the injury (T1) and between 5-7 days after the full RTP (T2). Results show differences between T1 and T2 ($p \leq 0.05$) in low frequency (LF) power (n.u.) and high frequency (HF) power (n.u.), in low frequency/high frequency ratio (LF/HF ratio) and in HF power (ms^2). No statistical differences were found in LF power (ms^2). The LF power (n.u.) was significantly lower after injury compared with LF power (n.u.) values after full RTP, due to a disruption in the neuroanatomic pathway between the autonomic and cardiovascular systems. In HF power there was a significant difference between both moments with high values after injury. Although this finding does conflict with previous studies, they only report athletes with concussion and we focused on other types of musculoskeletal injuries. In LF/HF ratio significant differences were found between the two moments, with low values of the LF/HF ratio after injury that tends to increase after full recovery, not been consistently reported in prior literature, but justified with the results found in the HF power. Therefore, HRV can be used to detect an imbalance in the ANS, allowing an early identification of a non-traumatic musculoskeletal injury. Further research should be performed considering a wide range of musculoskeletal injuries and sports modalities.

Keywords: autonomic nervous system, musculoskeletal disease, soccer athlete, sympathetic nervous system.

Introduction

Soccer is one of the most practiced sports around the world, with an increasing trend in the number of amateur and semi-professional athletes in recent years (Szymski et al., 2022). This is a high-intensity sport that involves repeated movements - such as, changes of direction, sprints, jumps and accelerations/decelerations - requiring physical and technical robustness capable of responding to these demands (Brow et al., 2021; Sprouse et al., 2020). Hence, with the increased number of athletes, the number of injuries has increased proportionately, not only in the professional leagues, but also at the semi-pro and amateur level (Krutsch et al., 2021; Szymski et al., 2022).

The ethology of sports injuries is complex and multicausal, and arises from factors such as trauma, inadequate blood supply, muscle fatigue, excessive loads or repeated movements to which athletes are exposed during sports practice (Mugele et al., 2018; Kisser & Bauer, 2012; Gisselman et al., 2016). In soccer, about 92% of injuries occur in the four big muscles of the lower limbs (hamstrings, quadriceps, adductors, and calves) leading to a higher abandonment compared to many other sports (Krutsch et al., 2021).

After a musculoskeletal injury, the inflammatory process is one of the primary responses and the healing process is initiated through the autonomic nervous system (ANS) (Gisselman et al., 2016). The action from ANS also influence the blood supply, transport of metabolic substances and release of neuromediators involved in mechanotransduction in response to injury (Gisselman et al., 2016; Vitale et al., 2019). Also, the increase in baroreflex activity and the released of inflammatory mediators could be responsible for activating nociceptors at the site of the injury (Koenig et al., 2014; Gisselman et al., 2016; Thayer et al., 2012). Hence, an imbalance between the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS) may indicate a state of injury, with an increase in the sympathetic response and a decrease in parasympathetic activity, leading to changes in heart rate variability (HRV) indices (Gisselman et al., 2016; Vitale et al., 2019; Dong, 2016).

HRV is measured by the intervals between consecutive heartbeats. The evaluation of HRV is made through the QRS complex and the R-R intervals (interval between two consecutive R waves), more precisely through the electrical impulse that crosses the ventricles and includes the Q, R and S waves, which reflect the activity of the sinoatrial node and the autonomic influence (Portelli et al., 2019).

In the frequency domain, HRV is decomposed through oscillatory components of the heart which allows the formation of a spectrum that divides oscillations in 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). VLF are influenced by physical activity, being a marker of sympathetic activity, LF represents sympathetic and parasympathetic activity, with a predominance of sympathetic activity, and HF reflect vagal tone (Forte et al., 2019; Voss et al., 2015; Conder & Conder, 2014; Raffin et al., 2019; Portelli et al., 2019; Tanindi et al., 2015; Thayer et al., 2012; Nakamura et al., 2020). There is also the low frequency/high frequency ratio (LF/HF ratio) that reflects the general sympathetic-vagal tone, where an increase in the LF/HF ratio represents an increase in sympathetic activity and a decrease in parasympathetic activity, while a decrease in the ratio reflects an increase in parasympathetic activity and a decrease in sympathetic activity (Thomas et al., 2019; Dong, 2016).

The measurement of HRV can be performed using 24-hour Holter Electrocardiography. Yet, these devices present some limitations in terms of access costs, comfortability, and freedom of movement (Caminal et al., 2018; Vanderlei et al., 2008; Porto & Junqueira, 2009). Due to this, several devices were developed to assess HRV in a faster and more practical way - such as the wireless heart rate monitors - which allow the calculation of R-R intervals with a resolution of 1 ms (Caminal et al., 2018).

One of these devices is the heart rate monitor chest strap Polar H10, which allows the collection of HRV through a moistened elastic electrode strap placed under the chest muscle that identifies the electrical signals continuously transmitted by the heart and stores the data in a receiver (e.g., the Polar m200) connected via Bluetooth (Vanderlei et al., 2008; Gilgen-Ammann et al., 2019). This equipment has the same reliability and validity as the widely Holter monitors in the assessment of HRV in the time domain, frequency domain and in non-linear analysis even being recommended when the assessment involves bodily movements (Gilgen-Ammann et al., 2019).

With the increased number of injuries and the huge financial costs associated with them, clinical departments of the clubs are under additional pressure to keep the athlete at their maximum level and, in case of injury, to recover them in the shortest possible time (Shamji et al., 2021; Barcelona, F.C., 2018). Thus, it is essential for clinical departments to establish certain methods of early identification of a non-traumatic musculoskeletal injury to manage the athlete at an early stage of injury, reducing their stop time (Barcelona, F.C., 2018). Therefore, the aim of this study is to analyse the adaptations of the ANS after a musculoskeletal injury, obtained by measuring HRV in athletes in acute phase and after the return-to-play (RTP). We hypothesized that there is an alteration in HRV after a musculoskeletal injury, more specifically a decreased in HF power and LF power after injury and an increase in LF/HF ratio that tends to decline.

MATERIAL AND METHODS

PARTICIPANTS

A longitudinal study was carried out on a sample consisting of male individuals aged between 21 and 33 years old (mean age: 29.4 ± 3.31 years). Only the participants who suffered a recent musculoskeletal injury were considered for the study. The sample was collected at 3 semi-professional football clubs in the central region of Portugal. Inclusion criteria were athletes diagnosed with a recent musculoskeletal condition (± 72h post-injury) and without associated cardiac/respiratory (or other) complications. Subjects were informed about the purpose of the study and signed an informed consent form (Appendix 3). This study was conducted according to the Helsinki Declaration (World Medical Association [WMA], 2013), and all procedures were approved by the Polytechnic of Leiria Ethics Committee (N. º CE/IPLEIRIA/24/2021). Figure 2 shows the study flow diagram.

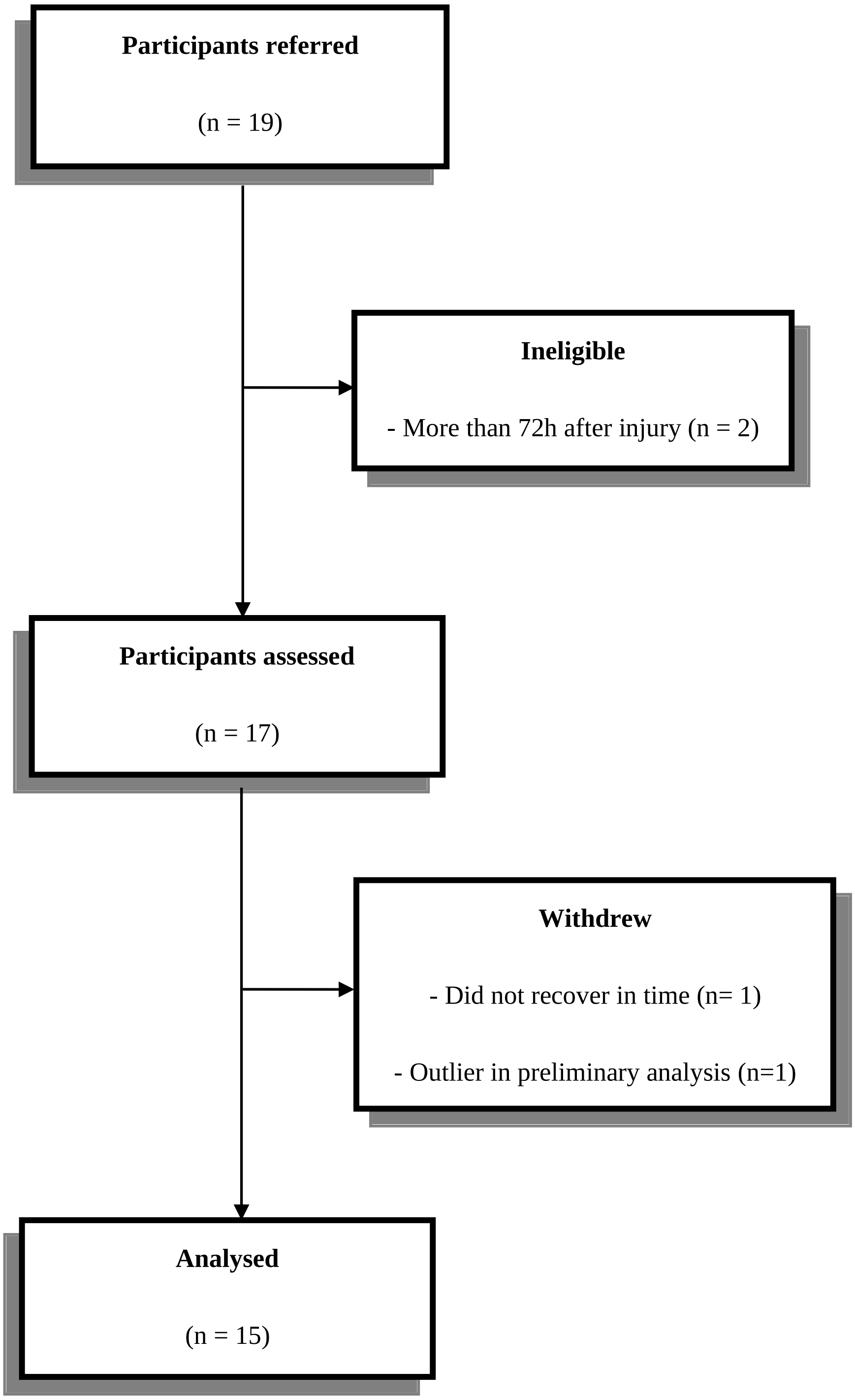


Figure 2. Study flow diagram.

Instruments

Heart rate variability was evaluated through Polar m200 and a polar heart rate monitor chest strap H10 (Polar Electro Oy, Kempele, Finland). The polar H10 was used to collect HRV measurements by detecting the R-R intervals, and the m200 sports watch was used as Polar H10 data logger. After data collection, all evaluations were exported to Polar Flow through the option “HRV data (CSV)” and analysed in the Polar Precision Performance Program software and Kubios HRV (Biosignal Analysis and Medical Imaging Group, Kuopio, Finland) in the frequency domain.

Procedures

In a first phase, the clinical departments were contacted to ascertain the availability for data collection. After acceptance, all participants filled out an Informed Consent to guarantee privacy, confidentiality and transparency of all collected data. Then, personal data (name, date of birth, contact information), the athlete´s medical history and the characteristics of the current injury were gathered to ensure the meet eligibility criteria (Appendix 3). HRV was evaluated using the Polar m200 and the Polar H10 (Polar Electro Oy, Kempele, Finland). The present protocol was developed based on previous studies (Bishop et al., 2017, Lima-Borges et al., 2018, Schmitt et al., 2013 and Hellard et al., 2011).

The data collection was performed in two moments. The first moment was within 72h after the injury (T1) and the second moment between 5-7 days after the full RTP (T2). Recordings were preferably carried out at the same time. The Polar m200 was placed on the subject’s left wrist and the Polar H10 (Polar Electro Oy, Kempele, Finland) around the chest, and they remain in a standing position with their arms at their sides. Before starting the assessment, the participant remained at rest for five minutes in a chair. The HRV assessment through Polar m200 and Polar H10 (Polar Electro Oy, Kempele, Finland) lasted 8 minutes and was always performed on the subject’s left arm. For study purposes, only the values obtained between the 2nd and 8th minute were considered for analysis. Figure 3 presents the schematic of study design.

The Polar Precision Performance Program Software and Kubios (Biosignal Analysis and Medical Imaging Group, Kuopio, Finland) were used to import, analyse and store the data (Hutchinson et al., 2017; Senthinathan et al., 2017; Schmitt et al., 2013). The analysis of HRV was performed in the frequency domain, dividing the oscillations into three groups: Very Low Frequency (0.0033 – 0.04 Hz), Low Frequency (0.04 – 0.15 Hz) and High Frequency (0.15 – 0.40 Hz), and expressed in absolute values (ms^2) and normalized units (n.u.) (Tanindi et al., 2015; Giles et al., 2016; Thomas et al., 2019). All collected and analysed data follow the recommendations of the Task Force of the European Society of Cardiology and North American Society of Pacing and Electrophysiology (Camm et al., 1996).

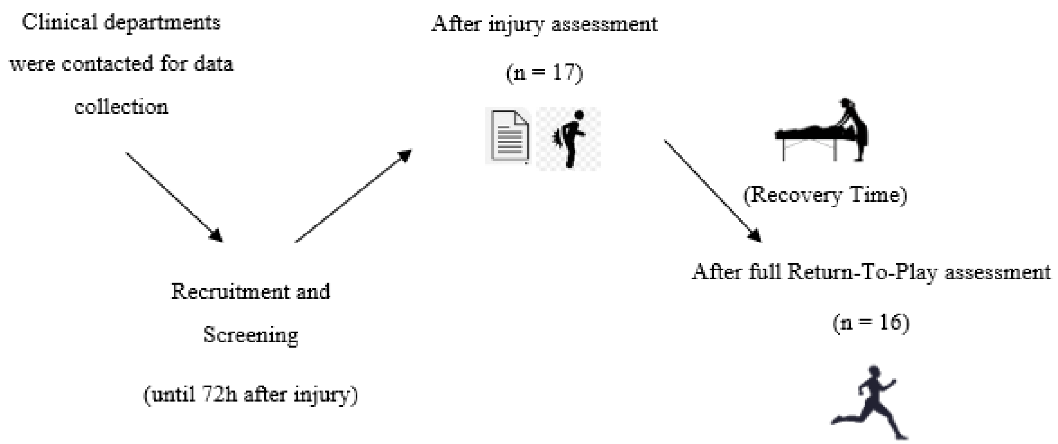


Figure 3. Schematic of study design.

STATISTICAL ANALYSIS

Preliminary Analysis

Initial data analysis revealed one outlier, who was removed from the study. A priori power analysis through G*Power (3.1.9.2) (Faul et al., 2007) was used to determine the required sample size considering the following input parameters: effect size d = 0.8; α =

0.05; statistical power = 0.9. The required sample size was 15, which was respected in the present study. The suggested size effect and remaining parameters were defined according to similar studies, that evaluated changes in HRV during exercise protocols (Perkins et al., 2017).

Statistical Analysis

Descriptive statistics - including mean and standard deviation - were calculated for all variables under analysis. A Shapiro–Wilk test (n < 50) was performed to analyse data distribution, and $p>0.05$ was considered as a normal distribution.

To analyse the differences between the two phases (after injury and after RTP) in HF power (n.u.) and LF power (n.u.) a paired samples t-test was used due to the normal distribution in Shapiro-Wilk test and to analyse the LF/HF ratio, HF power (ms^2) and LF power (ms^2) a Wilcoxon Test was used due to the non-normal distribution in Shapiro-Wilk test.

To compare the pre- and post-intervention, the magnitude of the effect was calculated using Cohen's d effect size and was interpreted as follows: < 0.20 (small), 0.20-0.79 (moderate) and > 0.80 (large) (Cohen, 1988). In the variables with non-normal distribution, the effect size was calculated based on the eta square value (η^2) according to the formula $\eta^2=Z^2/N$ (Lenhard & Lenhard, 2016; Fritz et al., 2012). Data analyses were performed using the IBM SPSS Statistics 24 (IBM, Armonk, NY). For all statistical procedures, the considered level of significance was 0.05.

RESULTS

CHARACTERISTICS OF SUBJECTS

Fifteen semi-professional athletes (29.4 ± 3.31 years old) successfully completed the study, presenting nine types of musculoskeletal injuries, of which six previously had a similar injury. Fourteen athletes performed three training sessions per week and one athlete performed four training sessions. Table 4 presents the baseline characteristics of all participants included in the present study.

Table 4. Baseline characteristics of the study participants included in the analysis.

Variables	All (n = 15)
Age in years, mean ± SD	29.4 ± 3.31
Regular medication, n (%)	0 (0)
Type of injury, n (%)	
Muscle tear isquiotibials	6 (40)
Muscle tear rectus femoral	2 (13.3)
Pubalgia	1 (6.7)
Tibiotarsal sprain	1 (6.7)
Knee sprain	1 (6.7)
Calcaneal trauma	1 (6.7)
Acromioclavicular traumatic injury	1 (6.7)
Peroneal fracture	1 (6.7)
Glenohumeral dislocation	1 (6.7)
Previous similar injury	
Yes, n (%)	6 (40)
No, n (%)	9 (60)
Training sessions weekly	
Three, n (%)	14 (93.3)
Four, n (%)	1 (6.7)

Notes: Data are expressed as mean ± standard deviation, count, or percentage as appropriate. Abbreviations: n, number; %, percentage.

Table 5 shows the differences between T1 and T2 in the studied variables. Differences between T1 and T2 ($p \leq 0.05$) in LF power (n.u.) and HF power (n.u.), in LF/HF ratio and in HF power (ms^2) were found. No statistical differences were found in LF power (ms^2).

Table 5. Differences between T1 and T2 on LF power (n.u.), HF power(n.u.), LF/HF ratio, LF power (ms^2) and HF power (ms^2) outcomes calculated with paired sample t-test and Wilcoxon Test.

Outcome	N	T1	T2	*p* value	η2	Effect size	95% CI
LF power (n.u.)	15	69.48 ± 17.27	83.65 ± 10.37	0.001		0.995	-0.078 -2.068
HF power (n.u.)	15	30.49 ± 17.24	16.32 ± 10.35	0.001		-0.996	-2.069 -0.077
LF/HF ratio (%)	15	3.52 ± 2.77	9.1 ± 7.96	0.001	0.699	3.044	
LF power (ms^2)	15	978.24 ± 655.85	1345.83 ± 1149.97	0.233	0.095	0.648	
HF power (ms^2)	15	703.81 ± 951.53	379.48 ± 555.3	0.017	0.379	1.563	

Notes: Data are expressed as mean ± standard deviation. Abbreviations: LF power, low frequency power; HF power, high frequency power; LF/HF ratio, low frequency/high frequency ratio, n, number; %, percentage; ms^2, milliseconds.

DISCUSSION

The objective of the present study was to analyse the activity of the sympathetic nervous system and the parasympathetic nervous system - two branches of autonomic nervous system - after a musculoskeletal injury and after full return-to-play in athletes, using heart rate variability. The use of HRV could be essential for clinical departments to identify a non-traumatic musculoskeletal injury in the early stages, reducing stop time, or to facilitate a safer RTP after injury.

Several studies have already demonstrated the role of the ANS in response to musculoskeletal injuries (Gisselman et al., 2016; Williams et al., 2017; Jewson et al., 2015; Grimm et al., 2005). The afferent vagal neurons communicate the somatic tissue damage to the brain, which result in the activation of the efferent vagal fibers increasing blood supply, transport of metabolic substances and the release of proinflammatory cytokines (Hellard et al., 2011; Gisselman et al., 2016; Esterov & Greenwald, 2017; Grimm et al., 2005). HRV is a rapid and noninvasive tool that can be used to detect an imbalance between the sympathetic and parasympathetic nervous system (Hellard et al., 2011; Williams et al., 2017), in which a reduction in HRV is associated to early signs of somatic tissue distress, even prior to pain or fully developed injury (Williams et al., 2017; Abaji et al., 2016; Lima-Borges et al., 2018). These findings agree with Jewson et al. (2015), who associated alterations in HRV to the development of a tendinopathy.

In the analysis of the HF power, there was a significant difference between both moments, with high values in the HF power after injury when compared with the results obtained after the full RTP. It is noted, however, that this finding does conflict with previous studies who refer a decreased in HF power after injury, due to an increase of the SNS activity and a decrease of the PNS activity (Abaji et al., 2016; Gall et al., 2004; Bishop et al., 2017; La Fountaine et al., 2019; Senthinathan et al., 2017; Pyndiura et al., 2020). This reduction was also observed by Hellard et al. (2011) during weeks characterized by an increased risk of muscular affections in elite swimmers and in response to overtraining stimulus. The somatic tissue damage leads to an ANS stimulation and a higher sympathetic activation that regulates the healing process, leading to a decrease in parasympathetic activity, and a decrease in the HF power (Abaji et al., 2016; Hellard et al., 2011; Gisselman et al., 2016; Williams et al., 2017). These divergences could be related to the different evaluation times of athletes and with the different types of injuries between studies since all cited studies focus on concussion.

In the current study, the LF power (n.u.) was significantly lower after injury compared with LF power (n.u.) values after full RTP. These results corroborated the studies of Gall et al. (2004), Bishop et al. (2017) and La Fountaine et al. (2019) who associated a decrease in the LF power after injury to a disruption in the neuroanatomic pathway between the autonomic and cardiovascular systems. Despite that, Hellard et al. (2011) and Senthinathan et al. (2017) refer an increase in the LF power, due to higher activation of the sympathetic nervous system.

In the analysis of the LF/HF ratio, significant differences were found between the two moments, with low values of the LF/HF ratio after injury that tends to increase after full recovery. This has not been consistently reported in prior literature. Some studies (Abaji et al., 2016; Hutchinson et al., 2017; Senthinathan et al., 2017) demonstrated a higher LF/HF ratio after injury that tends to decline with time and recovery. This difference could be justified with the results found in the HF power, since the ratio is dependent on the values of LF and HF power.

Although the present study contributes to our understanding of the HRV behaviour after a musculoskeletal injury, it has some limitations. Among them, is the use of different protocols to collect HRV between studies. More specifically, the timing of assessment after injury, the number of assessments, and the form of evaluation (e.g., some studies collect data at rest, standing or during submaximal exercise). Another limitation is that all cited studies focus on concussion and there are none that investigate the HRV behaviour after other types of musculoskeletal injuries, such as, muscle tears or pubalgia, that were presented by some subjects in this study.

Moreover, longitudinal and/or experimental studies are needed to further examine the effects of the analysed variables, to increase our knowledge about HRV, and to use them to detect early signs of somatic tissue distress, and so reducing athlete stop time, or to help the clinical departments to facilitate a safer RTP. Therefore, we suggest future studies considering a wider range of musculoskeletal injuries and sports modalities.

CONCLUSION

The present study suggests that after injury, an alteration in HRV is observed in the athletes. Specifically, a reduction in LF power and LF/HF ratio, and an increase of HF power was observed after injury. Despite the inherent limitations, our findings have important clinical implications since this is one of the first study to investigate the HRV alterations, in frequency domain, after different types of musculoskeletal injuries. The analysis of HRV in athletes could help the clinical departments to detect the development of a musculoskeletal injury and facilitate a safer return-to-play.

General Conclusions

The present work investigates the activity of the autonomic nervous system in a musculoskeletal injury in athletes. For that, we use heart rate variability, in frequency domain, to understand the sympathetic and parasympathetic nervous system behaviour after a musculoskeletal injury. The use of heart rate variability to detect early signs of somatic tissue distress or to do a safer return-to-play could be essential for clinical departments to improve their efficiency, to reduce costs, and to reduce the stop time of the athletes. So, we conduct a systematic review to understand the current literature, and then, based on the conclusions of that, we develop a longitudinal study in this area of investigation.

The systematic review demonstrate that heart rate variability decreases after injury. More specifically, we observed a decrease in high frequency power and in low frequency power, and an increase of low frequency/high frequency ratio. On the other hand, the second study demonstrates a reduction in low frequency power and in low frequency/high frequency ratio, as well as an increase in high frequency power after a musculoskeletal injury. Studies that investigate heart rate variability in a musculoskeletal injury are scarce, and one of the greatest limitations of the present work is that all studies included in the systematic review focused on concussion and do not explore other types of musculoskeletal injuries such as the ones presented in the longitudinal study.

Thus, the data presented in this work is extremely relevant, allowing the use of heart rate variability to understand the autonomic nervous system activity in a musculoskeletal injury and evaluated signals of somatic tissue distress to the early identification of a musculoskeletal injury and facilitate a safer return-to-play. We suggest future studies using heart rate variability considering a wide range of musculoskeletal injuries and sports modalities.

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Chapter 1

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APPENDICES

APPENDIX 1 - Oral communication certificate

XXII JORNADAS DA SOCIEDADE PORTUGUESA DE PSICOLOGIA DO DESPORTO

04 > 06 de novembro 2021

POLITÉCNICO DE LEIRIA | ESCOLA SUPERIOR DE EDUCAÇÃO E CIÊNCIAS SOCIAIS

DESPORTO E BEM-ESTAR

Psicologia do Desporto

CERTIFICADO

Para os devidos efeitos, certifica-se que:

a comunicação intitulada:

Heart rate variability behaviour in athletes after injury: a protocol for a systematic review and meta-analysis

da autoria de: _Gonçalo Flores, Diogo Monteiro, Fernanda Silva, Pedro Duarte-Mendes_, foi apresentada nas **XXII Jornadas da Sociedade Portuguesa de Psicologia do Desporto**, organizadas pelo Departamento de Motricidade Humana e Linguagens Artísticas da Escola Superior de Educação e Ciências Sociais do Politécnico de Leiria e pela Sociedade Portuguesa de Psicologia do Desporto, realizadas de 4 a 6 de novembro de 2021.

A Diretora dos Serviços Administrativos
(No uso da competência delegada pelo despacho n.º 8/2021, do Sr. Diretor da ESECS, de 27/05/2021)

Assinado por : **PAULA MARISA LOPES GOMES**
Num. de Identificação: 10279423
Data: 2021.12.09 12:09:49+00'00'

CARTÃO DE CIDADÃO

Campus 1 - Rua Dr. João Soares - Apartado 4045 2411-901 Leiria - Portugal – NIF: 506 971 244

APPENDIX 2 - Oral communication certificate

EUCAPA 2022

EUROPEAN CONGRESS OF ADAPTED PHYSICAL ACTIVITY 2022

Promoting inclusive sport & exercise opportunities for health and well-being

Faculty of Sport Sciences and Physical Education University of Coimbra

Oral communication certificate

This is to certify that Gonçalo Flores had an oral presentation entitled Heart rate variability behaviour in athletes after injury: a systematic review at **EUCAPA 2022 – European Congress of Adapted Physical Activity**, held at the **University of Coimbra, Faculty of Sport Sciences and Physical Education**, Portugal, on June on June 9th - 11th.

José Pedro Ferreira
Director Faculty of Sports Sciences and Physical Education

Aija Klavina
President European Federation of Adapted Physical Activity

APPENDIX 3 - CONSENTIMENTO INFORMADO, ESCLARECIDO E LIVRE PARA PARTICIPAÇÃO EM ESTUDOS DE INVESTIGAÇÃO NOS TERMOS DA NORMA N.º 015/2013 DA DIREÇÃO-GERAL DA SAÚDE (DE ACORDO COM A DECLARAÇÃO DE HELSÍNQUIA E A CONVENÇÃO DE OVIEDO)

Identificação do Investigador principal: Gonçalo Nuno da Silva Caldeira Flores.

Título do estudo: Comportamento da Variabilidade da Frequência Cardíaca em atletas após lesão.

Enquadramento: Este estudo é realizado no âmbito do Mestrado em Prescrição do Exercício e Promoção da Saúde, sob orientação do Prof. Dr. Pedro Alexandre Duarte-Mendes e do Prof. Dr. Diogo Monteiro.

Explicação do estudo: O objetivo deste estudo será estudar as adaptações do Sistema Nervoso Autónomo após uma lesão músculo-esquelética em atletas de futebol até duas semanas após a lesão.

Condições e financiamento: Este projeto não abrange o pagamento de deslocações ou de possíveis contrapartidas.
A participação neste estudo é de carácter voluntário e com ausência de prejuízos, assistenciais ou outros, caso não queira participar. Este estudo mereceu parecer favorável da Comissão de Ética do Politécnico de Leiria.

Confidencialidade e anonimato: Os dados recolhidos serão confidenciais, só a equipa de avaliação terá acesso a eles e serão recolhidos em formato totalmente anónimo (não registo de dados de identificação), cumprindo a recente legislação sobre utilização e acesso a dados pessoais. Os dados deste projeto serão armazenados em segurança e de uso exclusivo para o presente estudo, e jamais permitirão a identificação de qualquer elemento, face ao procedimento de anonimização anteriormente mencionado. No final, todas as informações recolhidas serão destruídas, exceto aquelas que por política de investigação tenham implicações relativamente às conclusões deste projeto, que serão armazenadas em segurança até 5 anos após o final do estudo. Todos os contactos feitos serão realizados em ambiente de privacidade. Se for seu desejo expresso os responsáveis pelo projeto poderão enviar-lhe os seus dados individuais.

Consentimento do participante

Declaro ter lido e compreendido este documento, bem como as informações verbais que me foram fornecidas. Foi-me garantida a possibilidade de, em qualquer altura, recusar participar no estudo "Comportamento da Variabilidade da Frequência Cardíaca em atletas após lesão" sem qualquer tipo de consequências. Desta forma, aceito participar neste estudo e permito a utilização dos dados, que de forma voluntária forneço, confiando em que apenas serão utilizados para fins científicos e publicações que delas decorram e nas garantias de confidencialidade e anonimato que me são dadas pelo investigador.

Nome: ____

Assinatura: ______________________________

Data: ___ /___ / _____

Nº processo:

Formulário recolha dados

Nome: ____

Data de Nascimento: __/__/__

Nº telemóvel: ______________________ **E-mail**: ____________________________

Histórico médico-cirúrgico:

____

Características da lesão atual:

____

Data da lesão: ___/___/_____

Data do RTP: ___/___/_____

Data primeira avaliação: ___/___/_____

Hora da avaliação: ___h___

Data segunda avaliação: ___/___/_____

Hora da avaliação: ___h___