Sleep and Heart Rate Variability in Athletes: A Systematic Review

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Abstract

Athletes are at considerable risk of mental health disorders, especially mood disorders characterised by emotion dysregulation. This vulnerability may be the consequence of a cascade of neurobiological factors, of which sleep disruption is a key feature. Sleep disturbance has been widely documented in this population and may lead to the impairment of emotion regulation. While emotion regulation is usually described by self-report measures, heart rate variability (HRV) has been used as an effective index of an individual's emotion regulation. Further, HRV has been linked to sleeping patterns. Research on emotion regulation in athletes and the effects of sleep disruption and emotion regulation of athletes is limited. This systematic review of sleep and HRV literature in the athlete population aims to identify if there is a consensus in the literature on the relationship of sleep and HRV in athletes. We included studies concerning both HRV and sleep in elite athletes published between 1996 and 2020. The methodologies of studies were independently assessed with adapted versions of three checklists; the Downs and Black (1998) (methodology), Lipinska et al. (2019) (sleep) and the Catai et al. (2020) (HRV). Study data was extracted with respect to design, year, participant characteristics and variables investigated. The search resulted in 23 relevant full-text articles, which were then grouped according to study design for analysis. Few studies gave any direct inference as to the relationship of sleep and HRV in the athlete population. Perceived sleep quality was found to have the strongest association with HRV parameters, which may indicate that HRV is sensitive to fluctuations in sleep when these fluctuations substantially impact perceived sleep quality. Furthermore, a number of studies gave evidence of HRV’s responsiveness to sleep disruption and improvement. However, the evidence is inconclusive. Ultimately, this review emphasises the need for more experimental research to investigate the influence of HRV on sleep in athletes and greater standardisation of methodological procedures in studies on athletes that incorporate sleep and HRV measures.

Introduction

Athletes are a population at risk of both sleep disruption and mental health difficulties (Rice et al., 2016). The degree to which athletes experience sleep disruption is important to consider as sleep is strongly related to emotion regulation efficacy, an integral aspect of mental health (Gupta et al., 2017; Palmer & Alfano, 2017). Heart rate variability (HRV), a physiological measure of autonomous activation, has been successfully used as a measure of emotion regulation (Palmer & Alfano, 2017). Therefore, sleep disruption could be the mechanism behind an athlete's mental health issues and HRV could theoretically serve as an index of the relationship between an athlete's sleep and mental state. Though sleep and HRV are often studied separately in athlete samples, there are no reviews investigating the relationship of sleep and HRV in athletes. As HRV is an easily obtainable physiological measure of emotion regulation and is potentially linked to athletes' sleeping patterns, this has important implications for clinical interventions and assessments for athletes suffering from mental health disorders. Therefore, the purpose of this study was to conduct a systematic review on sleep and HRV in the athlete population, to determine whether the literature indicates a consensus on how sleep affects HRV in athletes and to thus consider the potential implications of this for research on emotion regulation in athletes.

Athletes and Mental Health Risk

Studies have repeatedly identified athletes as vulnerable to mental health problems (Putukian, 2016; Rice et al., 2016; Rice et al., 2018; Schinke et al., 2018). Elite athletes especially show a greater risk of mental disorders, such as anxiety and depression, when compared to the general population (Rice et al., 2016). A variety of possible mechanisms have been suggested for this; neurobiological causes include traumatic brain injuries and overexertion, while others suggest mental stressors, such as performance anxiety and stress from the competitive nature of their profession (Lastella et al., 2014; Mainwaring et al., 2012; Putukian, 2016; Rice et al., 2016; Schinke et al., 2018; Venter, 2012). Injured athletes are potentially at greater risk, as they have both physical injuries and pressure to recover quickly, compounding to create a highly stressful mental state (Mainwaring, et al., 2012; Putukian, 2016; Rice et al., 2018;). Furthermore, athletes who are suffering from anxiety and mental health difficulties as a consequence of their injury, are often hesitant to seek help or to risk being diagnosed with mental illnesses, because of stigma and because they believe it may affect their careers. Further, many do not have healthy coping strategies and are accustomed to simply pushing through painful physical experiences (Putukian, 2016; Schwenk, 2000).

An athlete's ability to cope with stressful situations may be impaired by the physical nature of their sport. Studies have shown that contact sport athletes with a concussion and impaired sleep patterns scored higher than non-concussed athletes on the Beck Depression Scale, despite never being diagnosed with clinical depression (Gosselin et al., 2009; Mainwaring et al., 2012). Additionally, the most common disorders suffered by athletes are mood disorders, which are characterised by a failure to emotionally regulate, which is a valuable self-regulatory function that enables a person to better respond to stress-inducing stimuli (Palmer & Alfano, 2017; Rice et al., 2016). There are a variety of reasons, both neurobiological and mental, behind athletes' mental health risk and understanding the relationship between emotion dysregulation and mental health in athletes may be an important step in defining the nature of their symptoms and providing better treatment for mental health difficulties for these individuals. .

Emotion Regulation and Mental Health

Emotion regulation is a valuable skill for the maintenance of a healthy mental state. Successful emotion regulation enables the cultivation of helpful, adaptive emotions and the management of harmful, maladaptive emotions (Gross, 2013). Emotion regulation is defined as heterogeneous cognitive processes that influence the kind of emotions we feel, and when and how we feel them.An example of a common emotion regulation strategy is that of cognitive reappraisal, where a person attempts to change the emotion they are feeling, by reappraising the emotion eliciting stimuli in a more positive way (Palmer & Alfano, 2017). This includes conscious decisions to try to regulate emotions, as well as unconscious emotion regulation (Palmer & Alfano, 2017). Contrastingly, emotion generation is the term used to describe the process whereby an individual approaches, attends and appraises an emotionally evocative stimulus and feels an emotion in response (Palmer & Alfano, 2017). Emotion regulation allows individuals to better cope and adapt to serious and unpredictable life events, making it essential for functioning under novel stressors (van der Horn et al., 2016). Furthermore, inadequate emotion regulation is associated with a tendency to have weaker reactions to positive events, as well as a decreased likelihood to be able to identify certain situations in advance as negative or positive (Palmer & Alfano, 2017; Vandekerckhove & Cluydts, 2010; Zohar et al., 2005). Inadequate emotion regulation affects individuals' ability to experience positive emotions well and cope healthily with negative emotions. The importance of emotion regulation to mental health is further emphasised when considering how cognitive behavioural treatment often teaches patients emotion regulation strategies (Palmer & Alfano, 2017). It is therefore clear that successful emotion regulation plays a significant role in the maintenance of mental health. Therefore, it follows that individuals who are likely to have impaired emotion regulation functioning are consequently at mental health risk. This impairment in emotion regulation has been linked with sleep disruptions (Palmer & Alfano, 2017).

Sleep and Emotion Regulation

A growing body of literature suggests that sleep plays a fundamental role in an individual's healthy mental state, especially with regards to their generation and regulation of emotion (Gross, 2013; Palmer & Alfano, 2017). Disturbed sleeping patterns, as a consequence of irregular sleeping habits, mood disorders and a history of concussions, among other variables, are known to interfere with emotion regulation (Konrad et al., 2011; Palmer & Alfano, 2017; Perogamvros & Schwartz, 2015; Vandekerckhove & Cluydts, 2010; Zuzuárregui et al., 2018). Sleep-deprived individuals are more likely to generate negative emotions, emphasise and be more reactive to the negative affect of a stimulus, be less likely to successfully use reappraisal as an adaptation and struggle to employ regulation strategies to avoid negative situations (Palmer & Alfano, 2017; Vandekerckhove & Cluydts, 2010; Zohar et al., 2005). It has also been well established that impaired sleep patterns are usually comorbid with various psychopathological mood disorders, where individuals struggle with adaptive emotion regulation (Palmer & Alfano, 2017). Despite there being a consensus surrounding sleep's role in both maladaptive and adaptive experiences of emotion, advances in understanding precisely how emotional regulatory processes are affected by sleep are still nascent. This is because most indices of emotion regulation are based upon questionnaires and self-report measures, which are highly susceptible to subjectivity biases in participant responses (Choi et al., 2017). This reliance on self-report measures also complicates the generalisability of study outcomes, as different patients may describe their emotions in varying ways (Palmer & Alfano, 2017). Additionally, another undesirable confound is introduced if researchers explicitly ask their participants to emotionally regulate, as they may directly influence the tendency of participants to emotionally regulate (Palmer & Alfano, 2017). Consequently, it could be stated that sleep research on emotion regulation relying on self-report measures lacks a sufficiently objective measure capable of indexing both the success or failure of emotion regulation, the nature of the emotion eventually generated by the participant, all without introducing confounds that influence the participant's emotional response. A measure that has been suggested to do precisely the above is HRV.

HRV as a Potential Index of Emotion Regulation

HRV, defined as the changes in time intervals between consecutive heartbeats, indexes neurocardiac functioning and is typically used in evaluations of the autonomic nervous system (ANS) and human emotions (Bishop et al., 2018; Choi et al., 2017; Shaffer & Ginsberg, 2017). It is influenced by the interaction of the ANS, heart, blood pressure and other processes that form a part of the interdependent regulatory systems that help us adapt to both psychological and environmental challenges (Choi et al., 2017; McCraty & Shaffer, 2015; Shaffer & Ginsberg, 2017). Though there is skepticism with regards to the efficacy of identifying precisely how certain emotions are brought about by specific autonomic physiological processes, one could reasonably suggest a measurement of autonomic activation in order to make inferences about emotional functioning (Kreibig, 2010). HRV has therefore been widely theorized as a psychophysiological index of emotion regulation (Bishop et al., 2018; Choi et al., 2017; Shaffer & Ginsberg, 2017) Recent studies using HRV as an index of emotion regulation have shown convincing results (Bishop et al., 2018). These studies have found HRV to be a non-invasive, cost-effective and uncomplicated measure that could be applied to many protocols involving the cardiovascular system and ANS (Bishop et al., 2018). In their review of HRV, McCraty and Shaffer (2015) conclude that HRV can be used to index the functioning of various regulatory systems (McCraty & Shaffer, 2015). Emotion regulation, like all emotional processes, has a biological basis (Choi et al., 2017; Kreibig, 2010; Shaffer & Ginsberg, 2017). Evidence for HRV's ability to index emotion regulation can be found in that increased emotional processing by the prefrontal cortex has been linked to higher levels of resting HRV (Shaffer & Ginsberg, 2017). The aforementioned research suggests that HRV provides a more objectively reliable and generalizable measurement than subjective questionnaires and self-report methods, as it assesses emotional changes through changes in physiological signals (Choi et al., 2017). As emotion regulation research would benefit from an objective psychophysiological measure, studies researching HRV's feasibility and efficacy as an index of emotion regulation would be valuable. Furthermore, a measure of emotion regulation would be practical for clinical research, when considering how the ability to reliably emotionally regulate underpins mental health.

Emotion Regulation, Sleep and HRV in Athletes

Previously, we identified how athletes are at risk of mental health problems, that emotion regulation, a healthy mental state, and sleep are interrelated and that HRV can be used as a measure of emotion regulation. Two points bring these disparate variables together. Firstly, the disorders diagnosed within athlete populations are mainly anxiety and depression, disorders characterised by emotion dysregulation (Rice et al., 2016). This implies that whatever underlying mechanism of athletes' high mood disturbance rates, is likely to be related to emotion regulation. Secondly, athletes, in addition to being vulnerable to mental health problems, are also vulnerable to sleep disruption, a variable related to emotion regulation (Gupta et al., 2017; Lastella et al., 2014; Nedelec et al., 2018; Venter, 2012). In a recent review of elite athletes and their sleeping patterns, it was found that approximately one third to one half of these athletes are described as 'poor sleepers' (Gupta et al., 2017). Furthermore, the authors report that athletes are regular sufferers of insomnia and fragmented sleep (Gupta et al., 2017). This could be due to an array of reasons, such as discomfort from injuries, personal life stressors, and especially the stress of competitions (Gupta et al., 2017; Lastella et al., 2014; Venter, 2012). Regardless of what may be the cause of sleep disruption, it is a reasonable suggestion that the characteristic emotion regulation problems, underpinning the high mental illness rate among athletes, could be contextualised to some extent by the prevalence of sleep-related issues. Furthermore, as HRV has been shown to be a measure of emotion regulation, data on athlete's sleep and HRV could theoretically be used to consider the relationship of sleep on athletes' emotion regulation and would allow us to see what kind of role sleep has in an athlete's mental health state.

Rationale and Objective

The above identifies that athletes are at risk of mental health disorders, especially mood disorders characterised by emotion dysregulation. This vulnerability may be due to a cascade of neurobiological factors, including sleep disruption (Gupta et al., 2017; Mainwaring et al., 2012; Venter, 2012). Sleep disturbance has been widely documented in athletes and may lead to the impairment of emotion regulation. While emotion regulation is usually described by self-report measures, there is evidence of HRV being used as an objective physiological measure (Bishop et al., 2018; McCraty & Shaffer, 2015). These research domains – that of emotion regulation and the effects of sleep disruption and emotion regulation of athletes – are under-researched. Considering this, and the popularity of sport globally, research that investigates the effect of sleep on HRV in athletes would be contributing to knowledge in an important and under-researched area. By conducting a systematic review of sleep and HRV in athletes, we could identify the influence of sleep on HRV in this population, investigate how much of this research also comments on emotion regulation and therefore consider the potential implications of research on emotional regulation in athletes, informed by HRV. Existing systematic reviews that have been published tend to focus on the effect of HRV biofeedback on performance (Jiménez Morgan & Molina Mora, 2017), or merely describe the normal values of HRV in adults (Aubert et al., 2003; Nunan et al., 2010) or those suffering from mental illnesses (Koenig et al., 2016). The most similar systematic review to this study assesses HRV as a marker of chronic adaptation of physical exercise in athletes (da Silva et al., 2015), but not of emotion regulation. There are no systematic reviews looking at the contribution of sleep disruption to an individual's HRV in an athlete population.

Methods

Aim

The aim of this study was to conduct a systematic review of sleep and HRV in athletes, to determine if there is a consensus with regards to the relationship between sleep and HRV in this population.

Design

Objective, longitudinal, correlational, observational, cross-sectional, case study and cohort studies were included in the review. HRV is defined as the changes in time intervals between consecutive heartbeats. The process of searching and screening of articles and the exclusion criteria for analysis are discussed in more detail below. The systematic review followed a three-step methodological process; a literature search, methodological evaluation of the selected studies, and extraction of relevant data from selected studies.

Step 1: Literature Search

Stage 1: Database search

The first stage entailed accessing online databases (Africa-Wide Information, PubMed, PsycArticles, PsycINFO®, Web of Science, Cochrane Library) to extract literature. The final Boolean phrase was selected by four reviewers (A.T., G.L., L.S. and D.R.), and is detailed in Table 1, presented according to the search phrases associated with each of our main variables.

The phrase was adapted to the distinct Boolean grammar of database search engines. For example, the search phrase for Scopus ‘TITLE-ABS-KEY(athlete OR athletes OR sport OR sports OR sportsmen OR sportswomen OR player OR players)) AND (TITLE-ABS-KEY(sleep OR sleeping)) AND (TITLE-ABS-KEY("heart rate variability" OR HRV OR "autonomic cardiac activity")) AND NOT (TITLE-ABS-KEY(youth OR youths OR child OR children OR adolescent OR adolescents OR adolescence OR young OR pediatric OR paediatric OR "high school" OR "secondary school" OR "youth sports")’. The extracted citations were documented according to database and all duplicate citations were removed.

Table 1

Table Listing the Boolean Phrases to be Employed in the Initial Literature Search

Variable	Boolean Phrase
Athletes	(athletes OR players OR sport*) AND NOT (youth OR young OR children OR pediatric OR paediatric OR “high school”)
Sleep	sleep* AND NOT (youth OR young OR children OR pediatric OR paediatric OR “high school”)
HRV	(“heart rate” OR “heart rate variability” OR “HRV”) AND NOT (youth OR young OR children OR pediatric OR paediatric OR “high school”)
(Final Search Phrase)	(“heart rate” OR “heart rate variability” OR “HRV”) AND sleep* AND (athletes OR players OR sport*) AND NOT (youth OR young OR children OR pediatric OR paediatric OR “high school”)

The initial search was conducted by reviewers (A.T. and D.R.) on July 25th, 2020. The studies were extracted independently and then compared to confirm the accuracy and relevance of the chosen Boolean phrases. Subsequently, an additional search was completed by the same reviewers (A.T. and D.R.) on September 30th, 2020 to confirm that the final review has included the most recent publications.

Stage 2: Application of inclusion/exclusion criteria

The second stage of the literature search involved excluding citations that did not meet the inclusion criteria developed by the reviewers (A.T., G.L., L.S. and D.R.). The inclusion criteria were first applied to the titles of the obtained citations. An abstract and full-text screening followed to evaluate whether the final articles were relevant to the proposed study. The inclusion criteria were: 1) articles written in English, 2) published after 1996, 3) published in peer-reviewed journals, 4) human samples, 5) adult samples, 6) all articles including each of our main variables; HRV, sleep and athletes, and 7) participants are able-bodied athletes aged ≥18 years of age who are competing in either professional or amateur active sport at either the Olympic, international, national, club, or collegiate level.

The respective justifications for these inclusion criteria are as follows: 1) the final articles used in this proposed study were required to be in English as both primary reviewers (A.T. and D.R.) are only academically fluent in English and details might otherwise be lost in translation or misunderstood; 2) only articles published after 1996 were included as this is when most HRV measurements and calculations were standardized according to the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (Ernst, 2017); 3) only peer-reviewed journals were used to ensure that the research included is methodologically sound; 4) given that the focus of the review was on contact-sport athletes, studies that made use of animal samples were not relevant to our topic; 5) emotion regulation strategies have not yet matured in younger individuals, therefore their emotion regulation data would lack consistency and reliability, HRV and sleep values are different for adults, young adolescents and pediatrics, therefore combining these age cohorts is problematic; 6) articles that did not comment on HRV, sleep and athletes were not relevant; and 7) our research topic did not involve recreational sportsmen and much of the literature on athletes at mental health risk is on elite athletes who fall within this inclusion criterion (Rice, et al., 2018).

Stage 3: Reference mining

The final stage of the literature search evaluated the reference list of the included articles according to our inclusion criteria for citations that were relevant to the review.

Step 2: Methodological Evaluation

Once irrelevant articles were excluded, the methodology of the remaining articles was evaluated by a modified version of the Downs and Black checklist (Downs & Black, 1998;

Korakakis et al., 2018). This tool was developed to assess both randomised and non-randomised studies and provide an overall score of study quality. The Downs and Black (1998) Checklist (Appendix A) uses 27 yes-or-no questions to grade a study, where 'Yes' is graded as 1, while 'No' is graded as 0. The questions examine the quality of the study's research, the representativeness and generalisability of the findings, bias, confounds and statistical power, resulting in a total quality score out of 27.

Due to the wide range of study methodologies (case study, observation, intervention, experimental based, etc.), certain items of the Downs and Black (1998) checklist were not relevant to all articles in this review. Following consensus between A.T., G.L., L.S. and D.R., these items were marked as N/A. Using a strictly numeric-based rating scale has been found to be unreliable (O'Connor, et al., 2015), therefore, we evaluated studies using a subjective case-by-case approach, where methodological quality of articles were determined by comparing both the methodologies of the reported articles and the numeric ratings.

Because the Downs and Black (1998) checklist included no specific evaluation criteria for our variables of interest, we included additional checklists for assessing the methodology of gathering variable data. A sleep measurement checklist (see Appendix B) was created, based on guidelines from another systematic review on sleep (Lipinska et al., 2019). The Lipinska et al. (2019) tool had five items that explicitly checked (a) where the participants slept, (b) whether there was a control for alcohol, caffeine and drug consumption, (c) if there were controls for napping, (d) the inclusion of biological and self-report sleep measures and (e) whether sleep data was provided from sources other than wearables (smartwatches).

The HRV measurement checklist (see Appendix C) was adapted from another checklist outlining necessary procedures for capturing and processing HRV data of good quality (Catai et al., 2020). This checklist consisted of 30 items that focused on standardised HRV data collection and analysis methodology that would ensure the highest quality of collected HRV data.

The aforementioned methodological tools were collated into a single document that the two reviewers (A.T and D.R) used to conduct the evaluation of bias in the reviewed studies. The reviewers performed the analysis separately and met to discuss the ratings to ensure rigour and uniformity. If an article was scored differently by the two reviewers, the article was compared, discussed and rescored again. We planned to resolve discrepancies by consulting with a third or fourth reviewer (G.L or L.S), but this situation did not arise.

Step 3: Data Extraction

Data extraction was conducted by two reviewers (A.T. and D.R). An electronic spreadsheet was used to uniformly record the extracted data from each article. The spreadsheet headings included; 1) First author, 2) Journal, 3) Article title, 4) Database, 5) Year, 6) Type of study, 7) Sample used, 8) Outcomes investigated, 9) Results, 10) Conclusions. Thereafter, columns were added to record the score for every item of our various checklists and thereafter studies were grouped by design.

Data Analysis

Systematic reviews are characterized by descriptive evaluations of studies, using systematic methods, that compare and amalgamate findings (Harris et al., 2013). This includes describing the sample, methods, results and potential biases within the studies in a tabular form. The validity of study conclusions were assessed by evaluating their strengths and weaknesses. Subsequently, patterns that arose from the studies were examined by analysing their reported results and assessing any apparent trends. Because the included studies had significantly different methodologies, findings could not be combined into a homogenous group, and therefore a narrative analysis (Ferrari, 2015) was conducted according to study design.

Ethical Considerations

Plagiarism

All articles were cited in accordance with the 7th edition of the American Psychological Association's (APA) citation guidelines. The Turnitin™ software was used to assess the uniqueness of this review. If plagiarism was identified in an article, the article in question was to be processed with a plagiarism detection software and a report sent to the appropriate journal, although this situation did not arise.

Transparency

All individuals involved in the process of this study have been acknowledged and the authors acknowledge that there are no related funding or competing interests.

Bias

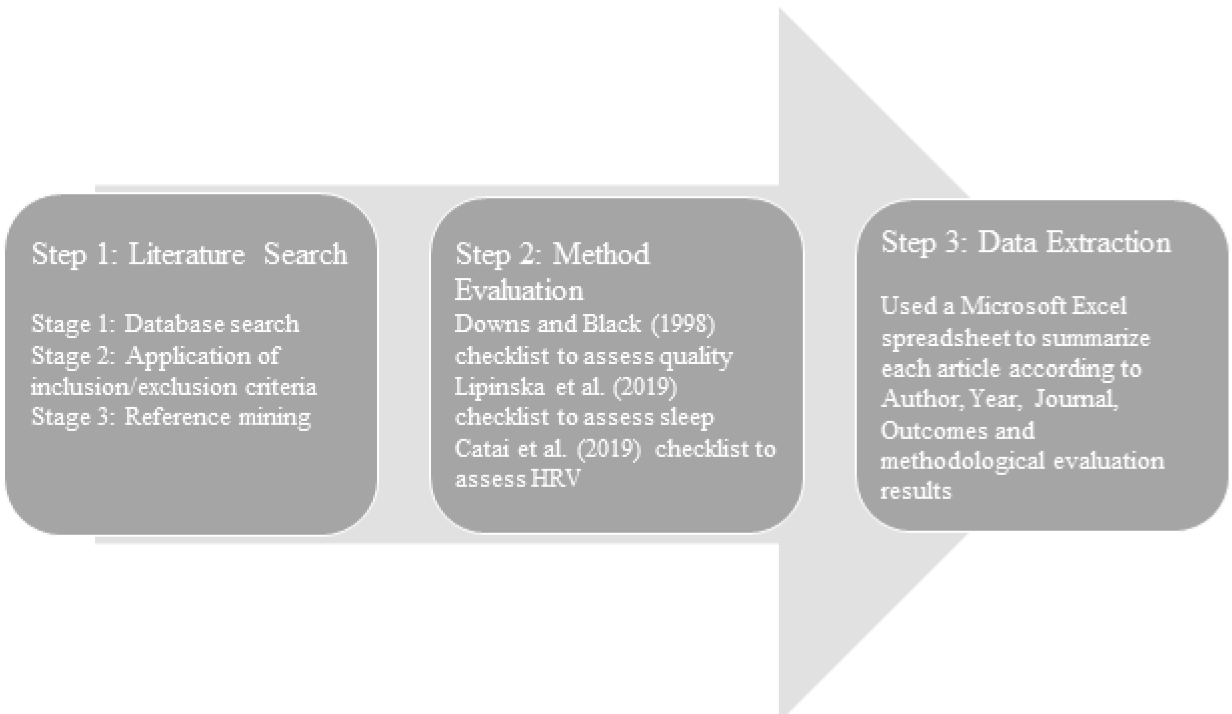
If bias was identified in a study, according to the Downs and Black (1998) evaluation tool, it would be reported to the appropriate journal, although this situation did not arise.

Results

Figure 1 depicts the structure of our results according to Steps 1 through 3 outlined in our Methods section.

Figure 1

Horizontal Flowchart Outlining Steps of the Review



Step 1: Literature Search

Stage 1: Database search

The first search yielded 366 articles and 328 after removal of duplicates. The second search added 6 articles, with no duplicates, bringing total articles screened to 334. Unique citations are summarised by database in Appendix D.

Stage 2: Application of inclusion/exclusion criteria

334 citations were screened using the exclusion criteria previously outlined. Following the application of the exclusion criteria to the titles of the studies, 304 articles were removed from the list. The exclusion criteria were then applied to the full-text and abstracts of the remaining studies, where a further 7 studies were excluded, leaving 23 studies remaining. Of

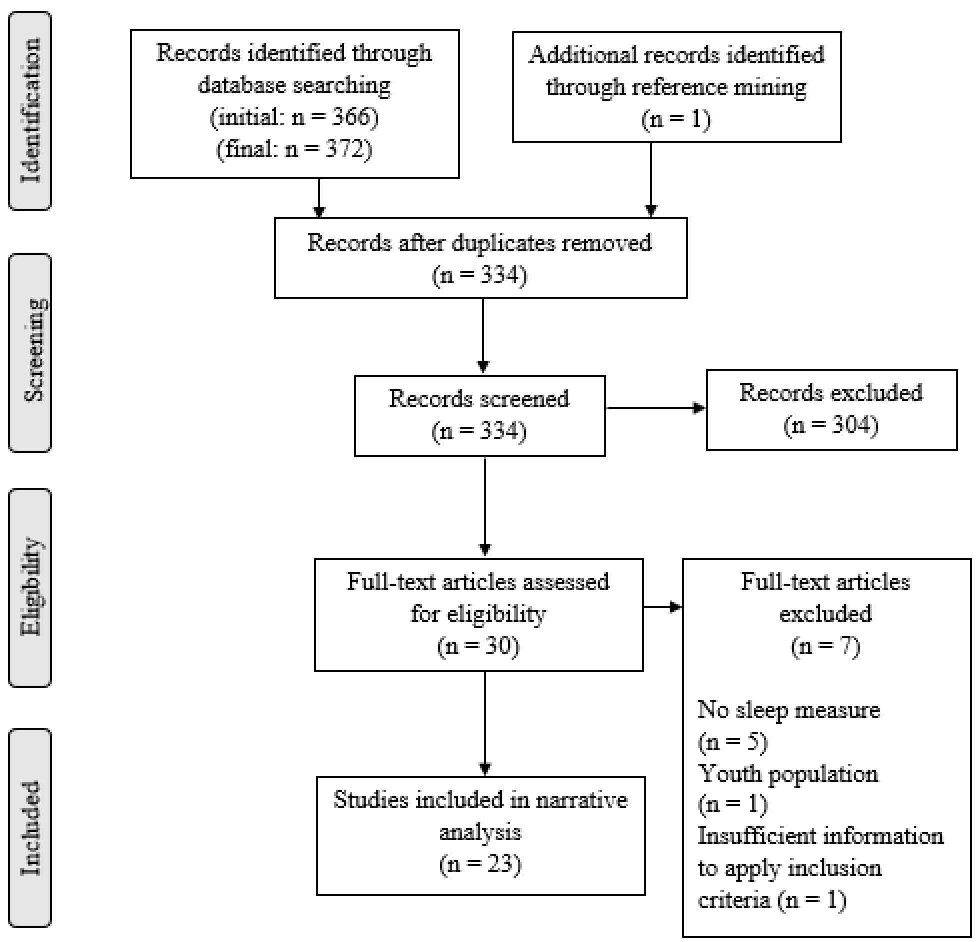
note, Eyal et al. (2019) was eliminated due to there being insufficient information for the application of the inclusion criteria, as it was an abstract based on conference proceedings.

Stage 3: Reference mining

Retrospective mining was then applied to the reference lists of the remaining citations. The reference list of Tibana et al. (2019) yielded one new article to be added; Rabbani, et al. (2018). This article met our inclusion criteria and therefore was added to the total list. Reference mining conducted on the aforementioned article yielded no additional studies. Stages 1 to 3 are summarised in Figure 2.

Figure 2

PRISMA Flowchart of the Article Selection Process



The final review included 23 articles. 5 were experimental studies (21.7%), 16 were observational (69.6%) and 2 were case studies (8.7%). Citation information for each study is presented in Appendix E.

Step 2: Methodological Evaluation

Downs and Black (1998) Checklist

Ratings of the studies according to the Downs and Black (1998) checklist criteria are summarised in Appendix F. Of note, there were items on the checklist that were irrelevant to observational studies, as they concerned interventions, which are not a feature of the observational study design. These items were graded as N/A.

Experimental studies performed moderately, satisfying 68.15% of the criteria on average. Only one experimental study conducted a power analysis, Douzi et al. (2019), and all studies only satisfied 33.33% of the external validity criteria. Experimental studies satisfied 66.67% of the confounding criteria, except for Aloulou et al. (2019), who only satisfied half. All of the experimental studies satisfied 70% of the reporting criteria, except for Aloulou et al. (2019) and Ramos-Campo et al. (2019), who satisfied 80%. Two studies, Douzi et al. (2019) and Rijken et al. (2016), satisfied 62.5% of the bias criteria, two studies, Al Haddad et al. (2012) and Ramos-Campo et al. (2019) satisfied 75% and one study, Aloulou et al. (2019) satisfied 87.5%.

Observational studies performed moderately, meeting 65.71% of the criteria on average. No observational studies performed a power analysis, and none satisfied any applicable external validity criteria, except Thomas et al. (2020), who satisfied 33.33%. All observational studies satisfied all of the bias criteria, except for Thomas et al. (2020), who only satisfied 75%. Most observational studies satisfied only half of the relevant confounding criteria, except for Buchheit et al. (2013), Costa et al. (2019c), Costa et al. (2019a), Flatt et al. (2018), Magiera et al. (2019) and Thorpe et al. (2017), who satisfied 75%. Half of the observational studies satisfied 75% of the reporting criteria. The rest satisfied 87.5% of the reporting criteria, except for Rabbani et al. (2018) and Thomas et al. (2020), who satisfied 62.5% and 90%, respectively.

Overall, case studies performed poorly, only satisfying 54.63% of the criteria on average. Both case studies satisfied only 33.33% of the external validity criteria and neither performed a power analysis. One study (Demarzo et al., 2015) satisfied only 50% of the reporting criteria and the other (Tibana et al., 2019) only 60%. Demarzo et al. (2015) satisfied 71.43% of the bias criteria and 50% of the confounding criteria, while Tibana et al. (2019) satisfied 75% of both the bias and confounding criteria.

Importantly, every article across all designs performed poorly in external validity and power domains, except for Douzi et al. (2019), which was the only article to conduct a power analysis.

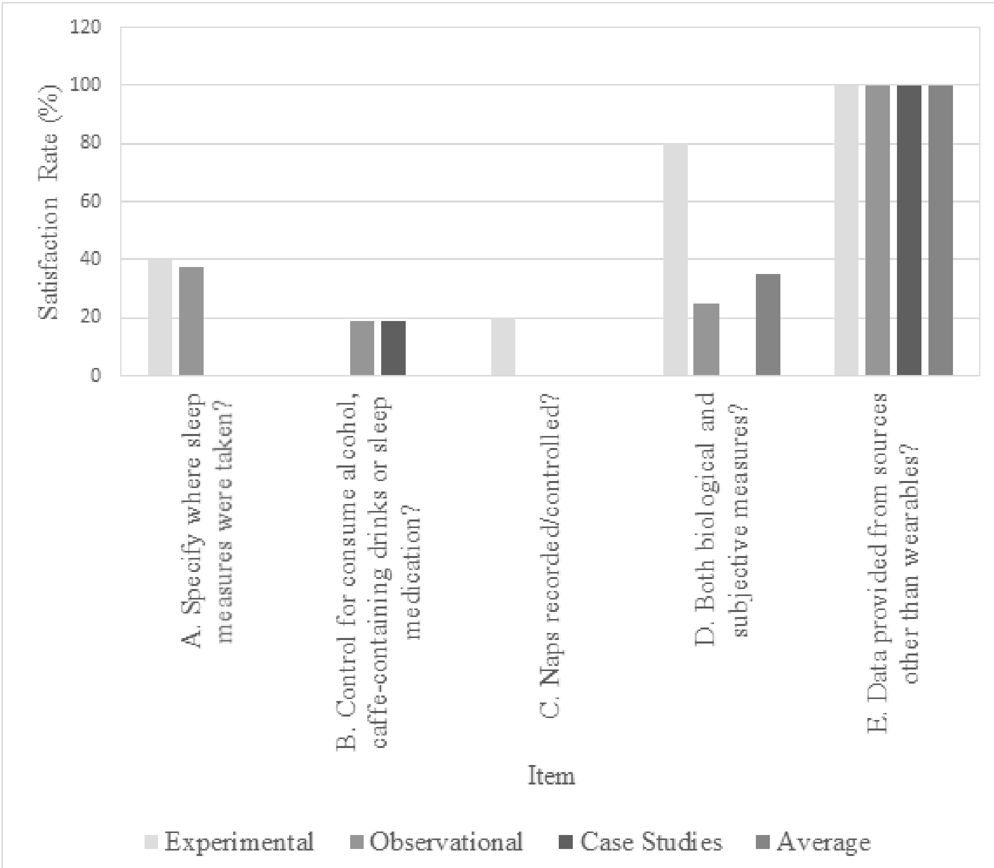
Lipinska et al. (2019) Sleep Measurement

No article received a perfect score, meaning that studies were not strong in their assessment of sleep (see Figure 3). The satisfaction rate for each item of the Lipinska et al. (2019) checklist are as follows: slightly more of the experimental studies than the observational studies (40% vs 37.5%, respectively) satisfied the criteria for item A, but no case studies did. No experimental studies and the same proportion (18.75%) of the observational studies and case studies satisfied the criteria for item B. Only 20% of the experimental studies satisfied the criteria for item C. A high proportion (80%) of the experimental studies, while only a quarter of the observational studies satisfied the criteria for item D. All studies satisfied the criteria for item E. The average satisfaction rates for items A-E were 25.83%, 12.5%, 6.67%, 35% and 100%, respectively. These satisfaction scores are depicted graphically in Figure 3.

Figure 3 emphasizes how poorly articles scored on the sleep scale, with only a few studies of every design satisfying items A through D. Across all designs, studies only performed well when regarding their use of sources other than wearables; all provided data from a device or established self-report scale designed to acquire sleep accurately rather than a smartwatch. This could indicate that this item (item E) has weak discriminatory validity, but also the unpopularity of using wearables in sleep and HRV research. Item C fared the poorest, with a total satisfaction rate of only 4.3%, meaning that the majority of the studies did not control for napping behaviour in their sleep measurement. The satisfaction of the Lipinska et al. (2019) sleep criteria is summarised in Appendix G.

Figure 3

Bar Graph Depicting Satisfaction Rate for Sleep Measurement Tool



Catai et al. (2020) HRV Measurement

Overall, studies performed at varying levels for the Catai et al. (2020) checklist. The satisfaction and overall satisfaction rate of each item is presented in Appendix H and Appendix I, respectively.

Most studies struggled with the control of noise, room temperature and humidity of the collection environment (satisfaction rates of 17.39%, 4.35% and 4.35% respectively). Additionally, few studies controlled/recorded the interactions and distractions of participants (satisfaction rates of 18.18% and 5%, respectively), no studies recorded occurrences such as sneezes, coughs or movement and few recorded clinical events (dizziness, blurred vision, etc.) (satisfaction rates of 0% and 4.35%, respectively). Most studies did not report the number of beats in which the HRV analysis occurred or described the stationarity criteria of R-R interval times series (satisfaction rates of 13.04% and 4.35%, respectively).

Most studies controlled for the general health of the participants and gave a description of the participants' dynamic/rest during collection (satisfaction rates of 73.91% and 86.96%, respectively). The devices and software used to collect data and total length of signal acquisition time were reported in most cases (satisfaction rates of 95.65%, 86.96% and 86.96%, respectively). Most studies described/controlled for the acquisition of other simultaneous signals, gave a description of the selected sample of data to be processed and reported on the software used in the analysis (satisfaction rates of 100%, 86.96% and 86.96%, respectively).

Generally, observational studies performed better than experimental studies, although the trends followed were similar. Overall, case studies performed notably more poorly than the observational and experimental studies, although the small number of case studies may not allow for a trend to be accurately established, which therefore affects these comparisons. Overall, HRV was not well measured or reported.

Step 3: Data Extraction

Sleep Quality

The majority of studies did not specify where participants slept, with 3 studies measuring sleep in a home environment, 2 studies in a sleep laboratory, 2 in a hotel and 1 in a sports camp environment. Therefore, the sleep environment for many studies was controlled, but did have the advantage of ecological validity While 3 of the 23 final studies analysed used both objective and subjective (self-report) sleep measures, 6 used only objective (4 actigraphy-only and 2 with actigraphy and polysomnography) and 14 used only subjective sleep measures. Regarding self-report measures, 8 studies utilized a preset Likert scale to measure sleep quality (5-7 points), 3 studies utilized the Pittsburgh Sleep Quality Index (PSQI), while others used the Total Quality Recovery action (TQRact) scale, Spiegal Sleep Quality Perception Questionnaire, Hooper Index or Karolinska Sleep Diary (1 per study). Bisschoff et al. (2016) also included a subjective measure of sleep quantity in hours. 2 studies utilized polysomnography, measured in 30-second epochs. 6 studies utilized actigraphy, but only 2 gave explicit time windows of 30-second epochs (Sekiguchi et al., 2019) or 60-s epochs on an hour-by-hour basis (Costa et al., 2019b).

HRV

All articles based their HRV measures on the standard deviation of the R-R intervals of recorded cardiac activity, from devices that were established as reliable measurement tools. 11 studies used the natural logarithm of the root mean square of successive differences (lnRMSDD), while 11 used the linear method and therefore both high and low frequency recordings for analysis. Buchheit et al. (2013) analysed the vagal-related HRV index (lnSD1), while Thomas et al. (2020) analysed the standard deviation of the R-R intervals, and Costa et al. (2019c) analysed standard deviation of normalized R-R intervals. Articles either measured HRV as part of nocturnal cardiac activity (n=8), upon awakening (n=4), measurements at a standardised time, (n =9), or during, before, and after exercise (n=1). The resting period before taking HRV measures was always at least 5 minutes. Measures were either taken from a standardised time window, or measured for an extended period of time and windows extracted for analysis.

Discussion

Relationship of Sleep and HRV in Athletes

The aim of this study was to conduct a systematic review of HRV and sleep in athletes, to determine whether the literature indicates a consensus on the relationship between sleep and HRV in athletes, where the results could have implications for the measurement of emotion regulation in athletes. Results indicated that there is inconclusive evidence of the relationship between sleep and HRV in athletes, although there is tentative evidence that only when perceived sleep quality is affected, there is associated HRV change. This could indicate emotion regulation's connection to sleep and HRV. Emotion regulation has been identified as related to sleep, and therefore, if sleep was markedly altered to the point that a participant felt a change in sleep, which would therefore be reflected in sleep quality perception measures, it should also result in a change in HRV (Palmer & Alfano, 2017; Vandekerckhove & Cluydts, 2010). There was also some replication of sleeping patterns being related to HRV scores, which could be indicative of sleep's role in protecting emotion regulation (Vandekerckhove & Cluydts, 2010. The evidence for the aforementioned results shall be presented by explaining the patterns of HRV and sleep measures across the varying study designs and by analysing the various methodological issues of HRV and sleep measurement.

Experimental Studies

The experimental studies overall show mixed results with regards to sleep's influence on HRV, but also suggest a trend of HRV responding to changes in perceived sleep quality. One study by Al Haddad et al. (2012) reported improvements in perceived sleep quality and parasympathetic activation reflected by HRV measures. However, it did not report the datasets for these measurements, making any further inferences untenable. This study's methodology also had particularly low scores for sleep methodology (see Appendix G1), implying that their results need more evidence.

Rijken et al. (2016) concluded that a combined intervention of either HRV feedback or neurofeedback could possibly lead to changes in performance-related outcomes and stress reduction. Important to note in Rijken et al. 's (2016) results is not that the intervention improved sleep quality, but more that it seems that regardless of the intervention, an increase of HRV occurred alongside an increase in wellness measures, including sleep. This indicates strong evidence of the importance of healthy sleep as a component of a generally healthy mental state.

The pattern that changes in sleep need to impact perceived sleep quality for HRV to reflect these changes could also be found in Ramos-Campo et al.'s (2019) research. Though moderate morning exercise resulted in higher sleep efficiency according to actigraphy compared to vigorous morning exercise, there was no difference in perceived sleep quality or HRV across groups. Though this is against our prediction that sleep change should result in HRV change, this article also be interpreted to suggest that HRV is responsive to sleep only when perceived sleep quality is substantially changed. All other experimental articles showed little indication that HRV was able to respond to changes in sleep. Some studies included HRV measurements but did not discuss their results at all, as seen in Douzi et al. (2019) and Aloulou et al. (2019).

Observational Studies

Despite researching sleep and HRV in athletes, few observational studies made inferences about the relationship between sleep and HRV. Sekiguchi et al. (2019) found that lower HRV was strongly associated with an increase in the percentage of time spent in slow-wave sleep (SWS), but not with sleep consistency or total time spent sleeping. This implies that when autonomic cardiac activity is impaired, athletes spend a higher time in SWS, implying a greater need for physiological recovery. This reflects the bidirectional relationship of emotional and sleep , as increased sleep can be a response to emotional stress, which could be reflected by impairment in autonomic cardiac activity (Palmer & Alfano, 2017; Vandekerckhove & Cluydts, 2010; Zohar et al., 2005). This pattern of HRV responding to sleep disruption is emphasised in two studies. Costa et al.'s (2019b) findings indicated that exercise training conducted at night could disturb sleep patterns and that limited insignificant effects would be seen in HRV assessed during sleep. Notably, in this study there were no differences in subjective well-being. Costa et al. (2019a) found that the time of day for training (ie. training at night) and match location (ie. away matches) may cause significant disruption in sleep patterns according to actigraphy and cardiac autonomic activity. Notably, subjective well-being was lower on night training days where sleep duration decreased, again indicating the direct relationship between sleep, HRV and wellness in athletes.

As with the experimental studies, a pattern was found where HRV changed when perceived sleep quality was significantly and substantially altered. Flatt et al.'s (2018) results indicate that HRV was significantly higher ($p < 0.05$) when perceived sleep quality, stress and mood were better than average, when compared with when they were worse than average. Improved mood being related to higher HRV and better sleep could also indicate the importance of sleep in preserving emotion regulation and the healthy mental state of athletes. Perceived sleep quality was found to have the strongest association with HRV parameters, replicating the same trend as the experimental studies. This pattern was similarly repeated in another study; Flatt et al. (2019) found that significant reductions in HRV were preceded by reduced perceived sleep quality and energy levels as a result of travelling. As sleep is important for restoring the ability to effectively emotionally regulate, and considering the exhaustion of long flights, decreases in HRV paired with perceived sleep quality and a decrease in energy levels is in line with previous literature (Vandekerckhove & Wang, 2017).

Though some studies report positive relationships of HRV and perceived sleep quality, others report less substantial results, making the aforementioned claim ambiguous. Thomas et al. (2020) found that high-intensity exercise in the early evening did not disrupt subsequent sleep and improved overall sleep across objective measures. There were no significant differences found between conditions for actigraphy or subjective sleep quality ($p > 0.05$) and no differences in nocturnal HRV between conditions. Here we see that objective sleep measures changed slightly, while perceived sleep quality and HRV did not, which implies that sleep does not regulate HRV.

Bisschoff et al. (2016) found that subjective sleep quality insignificantly influenced HRV across different match periods in elite male badminton players. Thorpe et al. (2016) found that although all wellness outcomes - including sleep - decreased on post-match days compared with pre-match days, no substantial or significant changes in HRV were found. This contrasts with findings from Bisschoff et al. (2016), Flatt et al. (2019) and Thomas et al. (2020) that suggest that HRV is sensitive to changes in perceived quality. However, sleep quality only decreased on a particular day and not over a sustained period of time, which raises ambiguity regarding the idea that sleep quality is only able to influence HRV recordings when its change is substantial enough to affect *perceived* sleep quality and emphasises the need for research on this topic.

Some studies, such as Costa et al. (2019c) and Moreno et al. (2015), had significant individual variability in objective sleep measures, perceptions of sleep and HRV measures, which meant that their results were not generalizable and no inferences could be made with regards to the relationship of sleep and HRV in athletes. Others - Buchheit et al. (2013), Crowcroft et al. (2017), Magiera et al. (2019), Rabbani et al. (2018) and Thorpe et al., 2017 - focused specifically on measurement sensitivities and comparisons of monitoring tools or did not report enough relevant data pertaining to both sleep and HRV, as they only gave averages rather than the distribution of the variables in the dataset. Thorpe et al. (2015) found that sleep quality and HRV varied significantly from day to day but did not report the direction that sleep quality varied, thus making inferences inconclusive.

Case Studies

Demarzo et al. (2015) found substantial changes in perceived sleep quality, which influenced HRV. However, HRV increased as sleep decreased, within at least two time frames of their data. This also adds ambiguity to the idea that HRV is sensitive to changes in perceived sleep quality. Tibana et al. (2019) found no correlations between HRV with perceived sleep quality. HRV had no correlation with other recuperation subjective variables such as general well-being or stress. HRV also fluctuated during times when there was no change in perceived sleep quality, as well as no change in subjective wellness measures. The study authors did explicitly note that these findings are at odds with research by Flatt et al. (2018). This study also is in contrast with the literature on emotion regulation and HRV, which implies that HRV should have remained stable in accordance with the minimal changes of emotion and mood (Palmer & Alfano, 2017).

Both case studies emphasise the need for more research to be done on HRV and sleep in athletes, as they demonstrate that HRV has a poor or unclear ability to reflect changes in sleep. Furthermore, their results may not be generalizable, as both studies performed especially poorly on their methodological measures (see Appendix H and Appendix I). Demarzo et al. (2015) was only able to satisfy 5 of the 30 HRV criteria and Tibana et al. (2019) only 10.

Methodological Considerations

Downs and Black (1998) Checklist

The Downs and Black (1998) checklist identified three notable aspects across study designs. The first is that there was low external validity across all study designs. Second, only one study, Douzi et al. (2019), conducted a power analysis. This reduces the generalisability of findings in articles, as it is unknown whether the changes observed in the athletes' sleep and HRV recordings would be replicated across the larger population or whether there is enough power to detect significant differences. Third, most studies are observational in nature (n = 15). This led to many of the Downs and Black items being inapplicable to these studies, which were then removed so as to not hold a study to an inappropriate standard. The implications of this for overall findings, is that they must be interpreted with caution, due to the aforementioned methodological issues.

Lipinska et al. (2019) Sleep Checklist

Overall, studies performed poorly on the sleep measurement, which indicates a lack of standardised measurement in the sleep data gathered, or a lack of reporting these standards, thereby calling into question the reliability of the gathered data. Studies usually did not control for caffeine, alcohol or drugs and they often had no control on the location that participants slept in (13.8% and 34.8% satisfaction rate respectively). There were also issues with vague perceived sleep quality and sleep length self-report measures (eg. as a subset of a wellness questionnaire). This is very basic information; we cannot tell whether the participants got a full night but poor-quality sleep, just too little sleep or whether they had insomnia and gives little indication of the regularity of participant's poor sleep quality patterns. Other studies used very brief self-report sleep measures, such as a one item Likert scale, although these have been shown to be effective enough to monitor sleep quality (Claudino et al., 2019).

Catai et al. (2020) HRV Checklist

Many items on the Catai et al. (2020) HRV checklist were also satisfied by the majority of articles. Some, such as item 17 (satisfaction rate of 0%), which asks whether the article mentions participants sneezing or moving body parts, would typically go unmentioned if nothing unusual occurred with regards to sneezes, coughs, bodily movement and other occurrences. However, other items seem to be indicative of a lack of standardised procedures for reporting HRV data. For example, 21 articles did not mention verification of signal quality during processing. This should be something explicitly stated, as verification of the signal quality is necessary to ensure the reliability of data. Furthermore, no articles reported on the stationarity of the HRV measure. This could indicate a lack of standardised procedures for measuring and reporting HRV data. Considering that this checklist was developed in 2019, the modal year of studies in this review, it could also be that these procedures for HRV reporting have not been widely adopted yet.

Limitations and Future Directions

Although all articles included in our review assessed sleep and HRV in athletes, few of the articles directly discussed the relationship between these variables and so inferences had to be made based on their results. Due to the different study designs and methods, it was difficult to make inferences as to the relationship between sleep and HRV in athletes. The research incorporating sleep and HRV, is also new, with the modal year of studies and the development of our methodological checklist for HRV both being 2019, meaning standards of practice may not be widely used. Some of the items on the Downs and Black (1998) checklist, which was part of determining the quality of each of the studies included in our review, were inapplicable to studies that were not intervention-based. A better solution would perhaps have been to utilise separate methodological questionnaires based on each type of study, so that all questionnaire items are applicable to their respective study designs and therefore the overall numeric study quality score would be more accurate.

Conclusion

The aim of this study was to conduct a systematic review of sleep and HRV in athletes, to determine if there is a consensus on the relationship between sleep and HRV in this population. 23 articles were extracted and compared by study design. Most articles performed adequately on the Downs and Black (1998) checklist, but poorly on the Lipinska et al. (2019) sleep and Catai et al. (2020) HRV methodology checklists. Reviewing the extracted articles identified that there is little evidence of a consensus on sleep and HRV's relationship in the athlete's population. Though there is evidence that HRV reliably varies in response to objective sleep measures, there is more evidence across experimental and observational designs that HRV responds more sensitively when subjective sleep quality measures are substantially and significantly affected, which suggests that this relationship is not universal. The link of perceived sleep quality and HRV and also of sleep disruption of HRV is in keeping with emotion regulation research that posits the importance of sleep to guarding emotion regulation capacities. Case studies showed particularly unusual patterns of HRV, though this may be due to unique aspects of their individual participants. However, due to the mediocre sleep and HRV study methodology scores, the wide range of differing study designs, these trends are inconclusive.

Further experimental research with high standards of sleep and HRV methodology is required to investigate the exact influence of sleep on emotional regulation, measured using HRV, in athletes. This will have important implications not only for the assessment of sleep and recovery in athletes, but also for the potential of HRV to be used as an index of sleep and emotion regulation in the athlete population. Understanding this relationship is vital in monitoring and reducing mental health risk in this population.

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Appendix A

Modified Downs & Black (1998) Checklist for Measuring Study Quality

Reporting

1. Is the hypothesis/aim/objective of the study clearly described?
2. Are the main outcomes to be measured clearly described in the Introduction of the Methods section?
3. Are the characteristics of the participants included in the study clearly described?
4. Are the interventions of interest clearly described?
5. Are the distributions of principal confounders in each group of subjects to be compared clearly described?
6. Are the main findings of the study clearly described?
7. Does the study provide estimates of the random variability in the data for the main outcomes?
8. Have all important adverse events that may be a consequence of the intervention been reported?
9. Have the characteristics of patients lost to follow-up been described?
10. Have actual probability values been reported (e.g. 0.035 rather than <0.05) for the main outcomes except where the probability value is less than 0.001?

External validity

11. Were the subjects asked to participate in the study representative of the entire population from which they were recruited?
12. Were those subjects who were prepared to participate representative of the entire population from which they were recruited?
13. Were the researchers, places and facilities where the participants undertook the study representative of the treatment the majority of participants receive?

Internal validity - Bias

14. Was an attempt made to blind study subjects to the intervention they received?
15. Was an attempt made to blind those measuring the main outcomes of the intervention?
16. If any of the results of the study were based on “data dredging”, was this made clear?
17. In trials and cohort studies, do the analyses adjust for different lengths of follow-up of participants, or in case-control studies, is the time period between the intervention and outcome the same for cases and controls?
18. Were the statistical tests used to assess the main outcomes appropriate?

19. Was the compliance with the intervention/s reliable?
20. Were the main outcome measures used accurate (valid and reliable)?*
21. Were the participants in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited from the same population?
22. Were study subjects in different intervention groups (trials and cohort studies) or were cases and controls (case-control studies) recruited over the same time period?
23. Were study subjects randomised to intervention groups?
24. Was the randomised intervention assignment concealed from both participants and researchers until recruitment was complete and irrevocable?
25. Was there adequate adjustment for confounding in the analyses from which the main findings were drawn?
26. Were losses of participants to follow-up taken into account?

Power

27. Did the study mention having conducted a power analysis to determine the sample size needed to detect a significant difference in effect size for one or more outcome measures?**

Scores are given as follows:

1, yes; 0, no; 0, unable to determine, 0

Total quality score __/27

Score Ranges: Excellent (26–27); good (20–25); fair (15–19); and poor (≤14)

**Note.* Item 20 was altered to be scored out of 2 to incorporate both outcome measures (sleep and HRV).

***Note.* Item 27 was modified from "Did the study have sufficient power to detect a clinically important effect where the probability value for a difference being due to change is less than 5%?" for simplicity and applicability across study designs. This item was altered to be scored out of 2 to incorporate a power analysis for each outcome, sleep and HRV, in accordance with Korakakis et al., 2018.

Appendix B

Sleep Measurement Methodology Tool (Adapted from Lipinska et al., 2019)*

A. Sleep Location: Does article specify where sleep measures were taken?

B. Were participants asked not to consume alcohol or caffeine-containing drinks or sleep medication prior to participants/measurement?

C. Were naps recorded or controlled for prior to or during participation?

D. Were both biological and subjective self-report measures used?

E. Is sleep data provided from sources other than wearables?

**Note.* This was created by analysing the inclusion criteria of Lipinska et al. (2019) and extracting important indicators of high-quality sleep measurement.

Appendix C

HRV Measurement Methodology Tool (Catai et al., 2020)

1. Was the general health of the volunteer controlled/recorded?
2. Was the place where the research was carried out suitable to infer possibilities of control (internal, external)
3. Was there any control or recording of any noise in the collection environment?
4. Was the room temperature controlled/recorded?
5. Was the humidity of the environment controlled/recorded?
6. Was the time of the day in which the collection took place controlled/recorded?
7. Were the patients/volunteers familiarized with the collection environment before recording the data?
8. Was the circulation of people controlled or recorded?
9. Were there any guidelines or records about substance ingestion?
10. Were there any guidelines or records about physical activities?
11. Were the baseline values of the volunteers recorded?
12. Did the volunteers have a rest of at least 15 minutes prior to collection?
13. Was there a description of the volunteers' body position during the collection?
14. Was there a description of the volunteers' dynamic/rest during the collection?
15. Was there any control of the volunteers' interactions during the collection?
16. Was there any control of the volunteers' distraction during the collection?
17. Were occurrences (the subject sneezed, coughed, dozed or moved body segments) recorded before, during and after the collection?
18. Were clinical events (dizziness, blurred vision, arrhythmias, etc.) recorded/controlled during and after the collection?
19. Was the device with which the data were collected described?
20. Was the signal acquisition rate described?
21. Was the software used for acquisition described?
22. Was total length of the signal acquisition time described?
23. Was the acquisition of other simultaneous signals described/controlled?
24. Was the need for controlling or controlled volunteers' breathing checked?
25. Was the signal quality verified during processing?

26. Was the description of the selected sample of data to be processed described?
27. Was a need for editing and filtering the signal during processing described?
28. Was the software used in the analysis reported?
29. Was the number of beats or times window in which the analysis occurred reported?
30. Were the stationarity criteria of R-R interval times series described?

Note. This checklist was adapted to add possible answers of ‘Yes’, ‘No’, ‘Unmentioned’ and ‘Non-Applicable’ (N/A), in order to standardize responses across all the articles.

Appendix D

Number of Unique Citations Found in Each of the Database Searches

Database	Search 1	Search 2	Total
Cochrane Library	14	0	14
EbscoHost (Africa-Wide Information, PsycArticles, PsycINFO)	156	0	156
PubMed	94	2	96
Scopus	39	2	41
Web of Science	63	2	65
Total before removal of duplicates	366	6	372
Duplicates	(38)	0	(38)
Total after removal of duplicates	328	6	334

Appendix E

Citation Information Extracted from Articles Presented in Order of Year

Authors	Year	Journal	Title
Al Haddad et al.	2012	International Journal of Sports Physiology Performance	Effect of daily cold water immersion on heart rate variability and subjective ratings of well-being in highly-trained swimmers
Buchheit et al.	2013	Journal of Science and Medicine in Sport	Monitoring fitness, fatigue, and running performance during a pre-season camp in elite football players
Demarzo et al.	2015	Actas Espanolas de Psiquiatria	Mindfulness applied to high performance athletes: A case report
Moreno et al.	2015	Spanish Journal of Psychology	Individual Recovery Profiles in Basketball Players
Thorpe et al.	2015	International Journal of Sports Physiology and Performance	Monitoring Fatigue During the In-Season Competitive Phase in Elite Soccer Players
Bisschoff et al.	2016	Journal of Sports Science and Medicine	Relationship between autonomic markers of heart rate and subjective indicators of recovery status in male, elite badminton players
Rijken et al.	2016	Applied Psychophysiology and Biofeedback	Increasing Performance of Professional Soccer Players and Elite Track and Field Athletes with Peak Performance Training and Biofeedback: A Pilot Study

Thorpe et al.	2016	International Journal of Sports Physiology and Performance	Tracking morning fatigue status across in-season training weeks in elite soccer players
Crowcroft et al.	2017	International Journal of Sports Physiology and Performance	Assessing the Measurement Sensitivity and Diagnostic Characteristics of Athlete-Monitoring Tools in National Swimmers
Thorpe et al.	2017	International Journal of Sports Physiology and Performance	The Influence of Changes in Acute Training Load on Daily Sensitivity of Morning-Measured Fatigue Variables in Elite Soccer Players
Flatt et al.	2018	Sports	Association between Subjective Indicators of Recovery Status and Heart Rate Variability among Division-1 Sprint-Swimmers
Rabbani et al.	2018	Physiology and Behaviour	Monitoring collegiate soccer players during a congested match schedule: Heart rate variability versus subjective wellness measures
Tibana et al.	2019	Sports	Monitoring Training Load, Well-Being, Heart Rate Variability, and Competitive Performance of a Functional-Fitness Female Athlete: A Case Study
Sekiguchi et al.	2019	Journal of Sleep Research	Relationships between Resting Heart Rate, Heart Rate Variability and Sleep Characteristics Among Female Collegiate Cross-Country Athletes
Douzi et al.	2019	BMC Research Notes	Effect of partial-body cryostimulation after training on sleep quality in professional soccer players
Aloulou et al.	2019	Journal of Sleep Research	The effect of night-time exercise on sleep architecture among well-trained male endurance runners

Costa et al.	2019	International Journal of sports Physiology and Performance	Does Night Training Load Affect Sleep Patterns and Nocturnal Cardiac Autonomic Activity in High-Level Female Soccer Players?
Costa et al.	2019	Plos One	Intra-individual variability of sleep and nocturnal cardiac autonomic activity in elite female soccer players during an international tournament
Costa et al.	2019	Chronobiology International	Sleep patterns and nocturnal cardiac autonomic activity in female athletes are affected by the timing of exercise and match location
Flatt et al.	2019	Journal of Science and Medicine in Sport	Effects of consecutive domestic and international tournaments on heart rate variability in an elite rugby sevens team
Magiera et al.	2019	Journal of Human Kinetics	Changes in Performance and Morning-Measured Responses in Sport Rock Climbers
Ramos-Campo et al.	2019	Physiology and Behavior	Effects of hour of training and exercise intensity on nocturnal autonomic modulation and sleep quality of amateur ultra-endurance runners
Thomas et al.	2020	European Journal of Applied Physiology	High-intensity exercise in the evening does not disrupt sleep in endurance runners

Appendix F

Tables Depicting Satisfaction Rate of Downs and Black (1998) Critiera

Table F1

Downs and Black (1998) Checklist Scores for Experimental Studies

Article Citation	Reporting Score	External Validity Score	Bias Score	Confounding Score	Power Score	Total Score
Al Haddad et al. (2012)	7/10 (70%)	1/3 (33.33%)	6/8 (75%)	4/6 (66.67%)	0/2 (0%)	18/27 (66.67%)
Aloulou et al. (2019)	8/10 (80%)	1/3 (33.33%)	7/8 (87.5%)	3/6 (50%)	0/2 (0%)	19/27 (70.37%)
Douzi et al. (2019)	7/10 (70%)	2/3 (33.33%)	5/8 (62.5%)	4/6 (66.67%)	2/2 (100%)	20/27 (74.07%)
Ramos-Campo et al. (2019)	8/10 (80%)	1/3 (33.33%)	6/8 (75)%	3/6 (50%)	0/2 (0%)	18/27 (66.67%)
Rijken et al. (2016)	7/10 (70%)	1/3 (33.33%)	5/8 (62.5%)	4/6 (66.67%)	0/2 (0%)	17/27 (62.96%)

Table F2

Downs and Black (1998) Checklist Scores for Observational Studies

Article Citation	Reporting Score	External Validity Score	Bias Score	Confounding Score	Power Score	Total Score
Bisschoff et al. (2016)	7/8 (87.5%)	0/2 (0%)	5/5 (100%)	2/4 (50%)	0/2 (0%)	13/21 (61.9%)
Buchheit et al. (2013)	6/8 (75%)	0/2 (0%)	5/5 (100%)	3/4 (75%)	0/2 (0%)	14/21 (66.67%)
Costa et al. (2019b)	7/8 (87.5%)	0/2 (0%)	5/5 (100%)	2/4 (50%)	0/2 (0%)	14/21 (66.67%)
Costa et al. (2019c)	6/8 (75%)	0/2 (0%)	5/5 (100%)	3/4 (75%)	0/2 (0%)	15/21 (71.43%)
Costa et al. (2019a)	6/8 (75%)	0/2 (0%)	5/5 (100%)	3/4 (75%)	0/2 (0%)	14/21 (66.67%)
Crowcroft et al. (2017)	6/8 (75%)	0/2 (0%)	5/5 (100%)	2/4 (50%)	0/2 (0%)	13/21 (61.9%)
Flatt et al. (2018)	7/8 (87.5%)	0/2 (0%)	5/5 (100%)	3/4 (75%)	0/2 (0%)	15/21 (71.43%)
Flatt et al. (2019)	7/8 (87.5%)	0/2 (0%)	5/5 (100%)	2/4 (50%)	0/2 (0%)	14/21 (66.67%)
Magiera et al. (2019)	7/8 (87.5%)	0/2 (0%)	5/5 (100%)	3/4 (75%)	0/2 (0%)	15/21 (71.43%)
Moreno et al. (2015)	6/8 (75%)	0/2 (0%)	5/5 (100%)	2/4 (50%)	0/2 (0%)	13/21 (61.9%)

Article Citation	Reporting Score	External Validity Score	Bias Score	Confounding Score	Power Score	Total Score
Rabbani et al. (2018)	5/8 (62.5%)	0/2 (0%)	5/5 (100%)	2/4 (50%)	0/2 (0%)	12/21 (57.14%)
Sekiguchi et al. (2019)	6/8 (75%)	0/2 (0%)	5/5 (100%)	2/4 (50%)	0/2 (0%)	13/21 (61.9%)
Thomas et al. (2020)	9/10 (90%)	1/3 (33.33%)	6/8 (75%)	3/6 (50%)	0/2 (0%)	19/27 (70.37%)
Thorpe et al. (2015)	6/8 (75%)	0/2 (0%)	5/5 100%	2/4 50%	0/2 (0%)	13/21 (61.9%)
Thorpe et al. (2016)	6/8 (75%)	0/2 (0%)	5/5 (100%)	2/4 (50%)	0/2 (0%)	13/21 (61.9%)
Thorpe et al. (2017)	7/8 (87.5%)	0/2 (0%)	5/5 (100%)	3/4 (75%)	0/2 (0%)	15/21 (71.43%)

Table F3

Downs and Black (1998) Checklist Scores for Case Studies

Article Citation	Reporting Score	External Validity Score	Bias Score	Confounding Score	Power Score	Total Score
Demarzo et al. (2015)	5/10 (50%)	1/3 (33%)	5/7 (71.43%)	2/4 (50%)	0/2 (0%)	13/26 (50%)
Tibana et al. (2019)	6/10 (60%)	1/3 (33.33%)	6/8 (75%)	3/4 (75%)	0/2 (0%)	16/27 (59.26%)

Appendix G

Tables Depicting Satisfaction of Lipinska et al. (2019) Sleep Criteria

Table G1

Satisfaction of Lipinska et al. (2019) Sleep Criteria for Experimental Studies

Article Citation	A. Does the article specify where sleep measures were taken?	B. Were participants instructed not to consume alcohol, caffeine-containing drinks, or drugs prior to participation/measurement	C. Were participants instructed not to nap prior to participation? Was there a control on napping behaviour?	D. Were both biological and subjective self-report measures used?	E. Is sleep data provided from sources other than wearables?
Al Haddad et al. (2012)	N	N	N	N	Y
Aloulou et al. (2019)	Y	N	N	Y	Y
Douzi et al. (2019)	N	N	N	Y	Y
Ramos-Campo et al. (2019)	Y	N	Y	Y	Y
Rijken at al. (2016)	N	N	N	Y	Y

Table G2

Satisfaction of Lipinska et al. (2019) Sleep Criteria for Observational Studies

Article Citation	A. Does the article specify where sleep measures were taken?	B. Were participants instructed not to consume alcohol, caffeine-containing drinks, or drugs prior to participation/measurement?	C. Were participants instructed not to nap prior to participation? Was there a control on napping behaviour?	D. Were both biological and subjective self-report measures used?	E. Is sleep data provided from sources other than wearables?
Bisschoff et al. (2016)	N	N	N	N	Y
Buchheit et al. (2013)	N	N	N	N	Y
Costa et al. (2019b)	Y	Y	N	Y	Y
Costa et al. (2019c)	Y	N	N	N	Y
Costa et al. (2019a)	Y	Y	N	N	Y
Crowcroft et al. (2017)	Y	N	N	Y	Y
Flatt et al. (2018)	N	N	N	N	Y
Flatt et al (2019)	N	N	N	N	Y

Article Citation	A. Does the article specify where sleep measures were taken?	B. Were participants instructed not to consume alcohol, caffeine-containing drinks, or drugs prior to participation/measurement?	C. Were participants instructed not to nap prior to participation? Was there a control on napping behaviour?	D. Were both biological and subjective self-report measures used?	E. Is sleep data provided from sources other than wearables?
Magiera et al. (2019)	Y	N	N	Y	Y
Moreno et al.l (2015)	N	N	N	N	Y
Rabbani et al. (2018)	N	N	N	N	Y
Sekiguchi et al. (2019)	N	N	N	N	Y
Thomas et al (2020)	Y	Y	N	Y	Y
Thorpe et al. (2015)	N	N	N	N	Y
Thorpe et al. (2016)	N	N	N	N	Y
Thorpe et al. (2017)	N	N	N	N	Y

Table G3

Satisfaction of Lipinska et al. (2019) Sleep Criteria for Case Studies

Article Citation	A. Does the article specify where sleep measures were taken?	B. Were participants instructed not to consume alcohol, caffeine-containing drinks, or drugs prior to participation/measurement	C. Were participants instructed not to nap prior to participation? Was there a control on napping behaviour?	D. Were both biological and subjective self-report measures used?	E. Is sleep data provided from sources other than wearables?
Demarzo, et al. (2016)	N	N	N	N	Y
Tibana at al. (2019)	N	N	N	N	Y

Appendix H

Tables of Satisfaction of Catai et al. (2020) HRV Criteria

Table H1

Satisfaction of Catai et al. (2020) HRV Criteria for Experimental Studies

Article Citation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Al Haddad et al. (2012)	Y	Y	N	Y	N	Y	Y	Y	N	Y	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y	Y	N/A	N	N	Y	N	Y	N	N
Aloulou et al. (2019)	Y	N	N	Y	Y	Y	Y	N/A	Y	Y	Y	Y	N/A	Y	N/A	N/A	N	N	Y	Y	Y	Y	Y	N	N	Y	N	Y	N	N
Douzi et al. (2019)	Y	Y	N	N	N	Y	Y	N	N	Y	Y	N	N	N	N	N	N	N	Y	N	N	N	N/A	N	N	N	N	N	N	N
Ramos-Campo et al. (2019)	N	N	N	N	N	N	N	N	Y	Y	Y	Y	N	Y	N	N	N	N	Y	N	Y	Y	N/A	N/A	N	Y	N	Y	N	N
Rijken et al. (2016)	Y	Y	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	N

Table H2

Satisfaction of Catai et al. (2020) HRV Criteria for Observational Studies

Article Citation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Bisschoff et al. (2016)	Y	N	N	N	N	N	Y	N/A	N	Y	Y	N/A	N/A	Y	N	N	N	N	Y	N	Y	Y	Y	N/A	Y	Y	Y	Y	N	N
Buchheit et al. (2013)	Y	N	N	N	N	N	N	N	Y	Y	N	N	N/A	Y	N	N	N	N	Y	N	N	N	N/A	N	N	Y	N	N	N	N
Costa et al. (2019b)	Y	N	N	N	N	Y	Y	N/A	Y	Y	Y	Y	N/A	Y	N	N	N	N	Y	Y	Y	Y	Y	N/A	N	Y	Y	Y	N	N
Costa et al. (2019c)	N	Y	N	N	N	Y	N	N/A	N	Y	N	Y	N/A	Y	N	N	N	N	Y	N	Y	Y	Y	Y	N	N	Y	Y	Y	Y
Costa et al. (2019a)	Y	N	N	N	N	Y	Y	N/A	Y	Y	Y	Y	N/A	Y	N	N	N	N	Y	Y	Y	Y	Y	N/A	N	Y	Y	Y	N	N
Crowcroft et al. (2017)	Y	N	N	N	N	Y	N	N/A	N	Y	Y	Y	Y	Y	N	N/A	N	N	Y	N	Y	Y	Y	N/A	N	Y	Y	Y	N	N
Flatt et al. (2018)	N	Y	N	N	N	Y	N	N/A	N	Y	Y	Y	Y	Y	N	N	N	N	Y	N	Y	Y	N/A	Y	N	Y	Y	Y	N	N
Flatt et al. (2019)	N	N	N	N	N	N	N	N	N	N	Y	N	Y	Y	N	N	N	N	Y	N	Y	Y	N/A	N	N	Y	N	Y	N	N
Magiera et al. (2019)	N	N	N	N	N	Y	Y	N	N	Y	Y	N	Y	Y	N	N	N	N	Y	N	Y	Y	N/A	N	N	Y	Y	Y	N	N

Article Citation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Moreno et al. (2015)	Y	N	N	N	N	Y	Y	n	N	Y	Y	N	Y	Y	N	N	N	N	Y	N	Y	Y	N/A	N	N	Y	Y	Y	N	N
Rabbani et al. (2018)	N	N	N	N	N	N	Y	N	N	Y	N	Y	Y	Y	N	N	N	N	Y	Y	Y	Y	N/A	N	N	Y	Y	Y	N	N
Sekiguchi et al. (2019)	N	N	N	N	N	N	Y	N	N	N	N	Y	N/A	Y	N	N/A	N	N	Y	Y	Y	Y	Y	N/A	N	Y	N	N	N	N
Thomas et al. (2020)	Y	Y	N	Y	N	Y	Y	Y	Y	Y	N	Y	N/A	Y	Y	Y	N	N	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	N
Thorpe et al. (2015)	Y	Y	Y	N	N	Y	Y	N	Y	Y	Y	N	Y	Y	Y	N	N	N	Y	N	Y	Y	Y	N	N	Y	Y	Y	N	N
Thorpe et al. (2016)	Y	Y	Y	N	N	Y	Y	N	Y	Y	Y	N	Y	Y	Y	N	N	N	Y	N	Y	Y	Y	N	N	Y	Y	Y	N	N
Thorpe et al. (2017)	Y	Y	Y	N	N	N	Y	Y	N	Y	Y	Y	Y	Y	Y	N	N	N	Y	N	Y	Y	Y	N	N	Y	Y	Y	N	N

Table H3

Satisfaction of Catai et al. (2020) HRV Criteria for Case Studies

Article Citation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Demarzo et al. (2016)	Y	N	N	N	N	Y	N	N	N	Y	Y	N	N	N	N	N	N	N	Y	N	N	N	N/A	N	N	N	N	N	N	N
Tibana et al. (2019)	Y	N	N	N	N	N	N	N	N	Y	Y	N	Y	Y	N	N	N	N	N	N	Y	Y	N/A	N	N	Y	Y	Y	N	N

Appendix I

Satisfaction Rate of Catai et al. (2020) HRV Criteria According to Study Design

Item	Experimental studies satisfied (%)	Observational studies satisfied (%)	Case studies satisfied (%)	Average Satisfaction Rate (%)
1. General health controlled/recorded?	100	62.5	100	87.5
2. Place research was carried out suitable to infer possibilities of control?	60	37.5	0	32.5
3. Control/recording of any noise?	20	18.75	0	12.92
4. Room temperature controlled/recorded?	40	6.25	0	15.42
5. Humidity of environment controlled/recorded?	20	0	0	6.67
6. Time of time of collection controlled/recorded?	60	62.5	50	57.5
7. Participants familiarized with the collection environment before recording?	60	68.75	0	42.92
8. Circulation of people controlled/recorded?	25	20	0	15

9. Guidelines/records about substance ingestion?	40	37.5	0	25.83
10. Guidelines/records of physical activities?	80	87.5	100	89.17
11. Baseline values recorded?	80	68.75	100	82.92
12. Rest of at least 15 minutes prior to collection?	60	60	0	40
13. Description of body position?	25	100	50	58.33
14. Description of dynamic/rest?	60	100	50	70
15. Control of interaction during collection?	0	25	0	8.33
16. Control of distraction during collection?	0	7.14	0	2.38
17. Occurrences recorded before, during and after collection?	0	0	0	0
18. Clinical events recorded/controlled during and after collection?	20	0	0	6.67
19. Device for data collection described?	100	100	50	83.33
20. Signal acquisition rate described?	60	31.25	0	30.42

21. Software for acquisition described?	80	93.75	50	74.58
22. Total length of signal acquisition time described?	80	87.5	50	72.5
23. Acquisition of other simultaneous signals described/controlled?	100	100	N/A	100
24. Need for controlling/controlled breathing checked?	0	18.18	0	6.06
25. Signal quality verified during processing?	0	6.25	0	2.08
26. Description of selected sample of data to be processed described?	80	93.75	50	74.58
27. Need for editing and filtering signal during processing described?	20	81.25	50	50.42
28. Software used in analysis reported?	80	87.5	50	72.5
29. Number of beats/times window of analysis reported?	20	12.5	0	10.83
30. Stationarity criteria of R-R interval times series described?	0	6.25	0	2.08