The use of heart rate variability in esports: A systematic review

Matthew R. Welsh [a,*], Emma Mosley [b], Sylvain Laborde [c,d], Melissa C. Day [a], Benjamin T. Sharpe [e], Rachel A. Burkill [f], Phil D.J. Birch [a]

[a] *Institute of Applied Sciences, University of Chichester, Chichester, UK*
[b] *Department of Rehabilitation and Sport Sciences, Bournemouth University, Bournemouth, UK*
[c] *Department of Performance Psychology, Institute of Psychology, German Sport University Cologne, Koln, Germany*
[d] *UFR STAPS, Normandie Université Caen, Caen, France*
[e] *Institute of Psychology, Business, and Human Sciences, University of Chichester, Chichester, UK*
[f] *International Federation of Esports Coaches, East Sussex, UK*

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ABSTRACT

Heart rate variability (HRV) is a psychophysiological measure of particular interest in esports due to its potential to monitor player self-regulation. This study aimed to systematically review the utilisation of HRV in esports. Consideration was given to the methodological and theoretical underpinnings of previous works to provide recommendations for future research. The protocol was made available on the Open Science Framework. Inclusion criteria were empirical studies, examining HRV in esports, using esports players, published in English. Exclusion criteria were non-peer-reviewed studies, populations with pre-existing clinical illness other than Internet Gaming Disorder (IGD), opinion pieces or review papers. In November 2022 a search of Web of Science, PubMed, and EBSCOHost identified seven studies using HRV in esports. Risk of bias was assessed using the Mixed Methods Appraisal Tool. Narrative review identified two primary uses of HRV in esports; stress response and IGD. A lack of theoretical and methodological underpinning was identified as a major limitation of current literature. Further investigation is necessary before making recommendations regarding the use of HRV in esports. Future research should employ sound theoretical underpinning such as the use of vagally mediated HRV and the robust application of supporting methodological guidelines when investigating HRV in esports.

Esports can be defined as the competitive play of specific video games that provides professional or personal development to the player (Pedraza-Ramirez et al., 2020). The esports industry has seen exponential growth in recent years (2015–2022; Sjöblom et al., 2019; Zhang & Liu, 2022), evolving from small scale tournaments to an industry worth $24.9 billion USD (Ahn et al., 2020). Esports players face similar competitive environments and stressors (e.g., live audience, opposition goading, and communication issues) to traditional sports (Hallmann & Giel, 2018; Smith et al., 2019), performing in large arenas in front of thousands of fans and competing for prize pools in excess of $30 million USD (McLeod et al., 2022). As the perceived demands of esports have increased in relation to its increased popularity (Butcher & Teah, 2023), so has demand for practitioners (e.g., sport psychologist) to support players; necessitating both applied practice and empirical research (Bányai et al., 2019). Practitioners play a fundamental role in enhancing player performance and maintaining their wellbeing in esports. Psychophysiological measures are increasingly utilised by practitioners to complement traditional sport psychology practices (Cooke & Ring, 2019; Fronso et al., 2017; Leis & Lautenbach, 2020) as triangulation of information can enhance understanding of player performance (Flick, 2017). Psychophysiological measures can offer insight to an individual's functioning (mind-body connection) and the objective nature of such measures may be particularly appropriate where disclosure or athlete knowledge could be limited. Heart rate variability (HRV) is a psychophysiological measure of particular interest in esports research due to its ability to index cardiac vagal activity which plays a key role in self-regulation (Laborde et al., 2017). Given previous research has identified that self-regulation may have a positive relationship with performance in both traditional sport (Jonker et al., 2011) and esports (Brevers et al., 2020; Trotter et al., 2021), HRV may address calls for psychophysiological indicators of esports performance (Leis & Lautenbach, 2020). Despite the clear potential of HRV and explicit calls for further research on biomarkers including HRV (Pedraza-Ramirez et al., 2020), there is currently no critical synthesis of the existing literature on

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HRV in esports to support researchers and practitioners. The aim of the present study was to systematically review the utilisation of HRV in esports research.

1. Heart rate variability

HRV is defined as the fluctuation in time interval between adjacent heart beats (Camm et al., 1996). The physiological origins of this mechanism lay in the autonomic nervous system (Berntson et al., 1997). This is split into two distinct parts; the sympathetic and parasympathetic nervous systems. Increases in sympathetic nervous system activity increase heart rate and consequently decrease the inter-beat interval. Increases in parasympathetic nervous system activity decreases heart rate, therefore, increasing the inter-beat interval. It is the interplay between these two systems that causes heart rate variability. Pharmacological blockade studies (Ackermann et al., 2021; Billman, 2013; Heathers, 2012; Reyes del Paso et al., 2013) have shown the parasympathetic system to be dominant over the sympathetic system, and due to its speed (milliseconds) can enact beat to beat changes (Thayer et al., 2012). Responses from the sympathetic system are, however, relatively slow (seconds; Thayer et al., 2012). Consequently, HRV is only able to index activity of the parasympathetic nervous system without additional measures (e.g., pre-ejection period; Sherwood et al., 1990). The parasympathetic nervous system is primarily controlled via the tenth cranial nerve, the vagus nerve (Brodal, 2010), and vagal activity regulating cardiac functioning has been termed cardiac vagal activity (Laborde et al., 2017). Contemporary literature has identified several HRV parameters with direct physiological association to the vagus nerve that can be referred to as vagally mediated heart rate variability (vmHRV). These are the root mean square of successive differences (RMSSD), percentage of adjacent NN intervals that differ by more than 50 ms (pNN50), and absolute power of high frequencies (HF ms^2). While there are a multitude of other HRV parameters, their direct physiological origins are unclear or require additional measures, therefore, the use of vmHRV has been highly recommended (Laborde et al., 2018; Mosley & Laborde, 2022; Thayer & Lane, 2000).

1.1. Vagal Tank Theory

There are five theories utilising cardiac vagal activity to predict human function (see Mosley & Laborde, 2022 for review). The most contemporary theory, the Vagal Tank Theory (Laborde et al., 2018), was developed from the Polyvagal Theory (Porges, 2007) and the Neurovisceral Integration Model (Thayer & Lane, 2009) to form a metaphorical basis to describe the functioning of cardiac vagal control. Authors of the Vagal Tank Theory suggest cardiac vagal activity acts as an indicator of how effectively self-regulatory resources are utilised (Laborde et al., 2018). Self-regulation is defined as the psychophysiological processes that enable goal directed behaviour and maintain health (Carver & Scheier, 2012). The Vagal Tank Theory further suggests there are three periods of particular interest; rest, reactivity, and recovery. At rest, high vmHRV would indicate the vagal tank is high which is associated with higher self-regulation leading to higher executive performance, stress management, emotional regulation, and overall better health. During reactivity (change from rest to event/stimuli) both an increase and decrease in vmHRV (vagal tank level) can be seen as adaptive depending on the situation. In instances of high metabolic demand, large vagal withdrawal is considered adaptive due to a greater self-regulatory response. However, when a task requires a lower level of physiological activity and instead relies on high executive functioning (i.e., esports) a smaller vagal withdrawal may be considered adaptive, as less self-regulatory resources are required. Finally at recovery (change from event to post-event), a faster recovery to or increasing past resting vmHRV would typically indicate strong self-regulation/adaption as the individual has the capability to cope with future events either in quick succession or with less self-regulatory demand than before. A slow

recovery or failing to recover to pre-event resting vmHRV would indicate poor self-regulation or maladaptation. It should be noted that this is only a generalised overview of the Vagal Tank Theory and interested readers are directed to the original work by Laborde et al. (2018) for further detail and nuances.

1.2. HRV in traditional sports

HRV has been utilised for a myriad of purposes within traditional sports psychology in both practice and research. This has included indexing psychological stress (Morales et al., 2019), cognitive performance (Gantois et al., 2020), pre-competitive anxiety (Ayuso-Moreno et al., 2020), biofeedback (Pagaduan, 2021), pain (Matylda et al., 2020), motivation (Korobeynikov et al., 2011), and recovery and overtraining (Dobson et al., 2020). Unfortunately, a recent scoping review of this existing literature in traditional sport has revealed a typical lack of theoretical underpinning leading to inconsistent measurement of HRV and consequently highly variable results (Mosley & Laborde, 2022). By focusing on only vmHRV results, a trend towards reduced vmHRV in instances of greater self-regulatory demand can be implied, including situations of pre-competitive anxiety (Pagaduan, 2021), psychological stress (Móra et al., 2022), overtraining (Hynynen et al., 2008), and pain (Britton et al., 2019). To deal with such stressors, researchers have primarily employed slow paced breathing with some additionally employing biofeedback via a visual representation of vmHRV (Mosley et al., 2023; Paul & Garg, 2012). A preliminary systematic review of biofeedback interventions would suggest that it is generally effective in increasing vmHRV, increasing sporting performance, and reducing anxiety (Pagaduan et al., 2022). Links have further been proposed between subjective measures of recovery and vmHRV (Flatt et al., 2017; Vacher et al., 2018), which may prove beneficial to researchers and coaches who wish to monitor holistic recovery in competition, training, and/or in response to other stressors (Mosley & Laborde, 2022). In general, this body of evidence would support the use of vmHRV in sport psychology, however, as previously noted further theoretically and methodologically informed research is needed before accurate recommendations can be made (Mosley & Laborde, 2022). At present, it is challenging to provide evidence-based guidance to practitioners. As a result, researchers have advocated for systematic reviews on the use of HRV in other domains (Mosley & Laborde, 2022).

In addition to theoretical recommendations, numerous methodological guidelines have been proposed. Original guidance was produced over two decades ago by a specialised task force (Malik, 1996) and while modern recommendations based upon current understanding have been developed (Catai et al., 2020; Laborde et al., 2017; Quintana & Heathers, 2014), these guidelines are not yet systematically applied across research. In recent years, fundamental changes in understanding HRV have occurred including the disassociation of the sympathetic nervous system, which is included as a measure within the original guidance (Malik, 1996). Contemporary research promotes the use of vmHRV as well as consideration of confounding variables such as participant age, time of day, respiration rate, and recording position (Catai et al., 2020; Laborde et al., 2017). Considering there are five theories and multiple methodological guidelines, disparity in the utilisation of HRV is somewhat expected. Therefore, theory is needed to underpin research and transparent methods are needed to collect data. By doing this, we can advance our understanding of vmHRV.

Within HRV research in traditional sports, there are several typical methodological constraints, however, esports may provide an alternative area of investigation to address these issues. A common problem in HRV research is artifacts caused by gross movement (Morelli et al., 2019) which is typical in many traditional sports. Esports are played in a static manner requiring fine motor control of the upper extremities (McGee et al., 2021). This means there is low gross movement, which in turn, may result in better data quality. A second limitation of HRV research in traditional sports is the impact of respiration rate on HRV

(Thayer et al., 2011). Due to a relatively low respiration rate even when at maximal performance exertion, esports again lends itself to higher quality data collection. Finally, there are a multitude of environmental factors that can affect HRV (Laborde et al., 2017), however, the ability to obtain quality HRV data in a naturalistic environment further identifies esports as an ideal arena for this type of research. Consequently, advancing our understanding of HRV in esports may not only elicit a method to objectively monitor self-regulation in this domain, but also lead to transferable findings in traditional sport.

2. Esports

Previous systematic reviews in esports have had several aims, with one of the most prevalent being the investigation of stress. Palanichamy et al. (2020) surmised that excessive esports playing time can cause psychological issues including social, emotional, and addiction problems. Chan et al. (2022) also suggest excessive esports has a generally negative effect on lifestyle including reduced quality of sleep and diet. Conversely, Leis and Lautenbach (2020) concluded results were generally mixed due to potential underlying theoretical and methodological issues within current esports stress literature; in some ways echoing the HRV literature (Mosley & Laborde, 2022). What is clear is there are numerous factors that may impact an esport players' self-regulation and performance. Bányai et al. (2019) suggest esports players face challenges comparable to traditional sports athletes and have similar psychological mindsets. The ability to regulate stress and emotions in-game can define an esport players' performace, potentially leading to clutch moments (instances of heightened performance under pressure; Otten, 2009). Understanding self-regulation preceding and during these moments may consequently help researchers and practitioners to predict performance. Therefore, to advance understanding, a theoretically and methodologically robust objective measure to monitor esport players' self-regulation is needed.

2.1. Demands of esports

Esport players face a plethora of stressors that can affect self-regulation both within and away from competition. Unsurprisingly, the frequency and intensity of such stressors peak around competitive matches, more so than during team or solo practice (Poulus et al., 2022). The most commonly reported stressors include personal performance, team issues, audience/opposition, social media, and life outside esports, while cognitive self-regulation strategies can be grouped into three main categories; emotion focused, problem focused, and avoidance coping (Leis et al., 2022; Poulus et al., 2022; Smith et al., 2019). Problem focused coping is typically the most used and most effective whereas avoidance coping is commonly used yet regarded as the least beneficial (Poulus et al., 2020, 2022; Smith et al., 2019). At present, limited traditional sport psychology tools have been employed in esports to promote effective cognitive self-regulation such as positive self-talk (Smith et al., 2019) and positive imagery (Brackette & Ayvazian, 2023), however, further efforts need to be made to best support performers. Greater use of psychological skills has been associated with higher cognitive self-regulation and consequently increased esports performance (Brevers et al., 2020; Trotter et al., 2021). Therefore, physiological measures of self-regulation such as vmHRV could potentially identify the effectiveness of psychological skills training and identify where self-regulatory coping strategies are required to enhance performance.

2.2. Physiological self-regulation

Although esports researchers are starting to build a clear understanding of cognitive self-regulation through qualitative enquiry, there is still a need to understand the physiological self-regulation of players (Kou & Gui, 2020). A recent systematic review of psychophysiological

stress in esports would suggest that esports players may exhibit a physiological stress response both during and post-competition (Leis & Lautenbach, 2020). However, further research is needed before conclusions can be made due to theoretical and methodological limitations of current research contributing to conflicting results (Leis & Lautenbach, 2020). Other psychophysiological measures of self-regulation such as cortisol (Schmidt et al., 2020) and blood pressure (Siervo et al., 2018) have been proposed in esports, however, their application within competition is limited. This is likely due to their intrusion on performance, highly specialised operation, and associated cost (Gerber et al., 2012; Koshy & Koshy, 2020). Consequently, HRV being non-invasive, simple to measure, and incurring a relatively low cost (Mosley & Laborde, 2022) may provide a convenient and unobtrusive measure of self-regulation in esports. Previous esports studies have utilised HRV as an indicator of many phenomena including stress (Chaput et al., 2011), fatigue (Andre et al., 2020), cognitive skill (Hisatsune et al., 2022), metabolic demand (Nicholson et al., 2020), and Internet Gaming Disorder (IGD; D. Lee et al., 2021). These studies suggest disparity in the way HRV has been utilised within esports, however, the variation in how HRV was collected and measured is still unknown. Moreover, it is also important to determine the methodological rigour underpinning existing HRV research in esports. Considering these factors may provide both clear methodological guidance and improve the rigour of future HRV research in esports.

To advance understanding, it is both timely and necessary to explore the methodological and theoretical foundations of previous esports research to ensure that issues observed in the broader HRV literature are not replicated when applied in esports research and practice. Therefore, further research is required to synthesise the use of HRV in esports and provide scholars with an informed direction for future investigation. The aim of the presentstudy was to systematically review how HRV has been utilised within esports research.

3. Method

3.1. Pre-registration

Our methodology was made publicly available on the Open Science Framework on the 12th of September 2022 and can be accessed here (https://osf.io/dzyk2). Science Direct was removed as a database due to its inability to support the number of Boolean operators in the stated search terms. No changes were made to the search terms as a result of initial searches.

3.2. Search strategy

For transparency, initial searches were completed on the 4th of August 2022 to identify database issues prior to commencement. Database searches commenced on the 16th of September 2022. A final repeated database search was conducted on the 23rd of November 2022 which included manual citation and reference searching of included papers, after which no new studies were considered for inclusion. A comprehensive literature search of online databases was completed following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses; Page et al., 2021) guidelines, encompassing Web of Science, PubMed, and EBSCOHost (narrowed to the most appropriate repositories for the research question; SPORTDiscus, PSYCHInfo, PSYCHArticles, SOCIndex, and institutional database). The search terms were structured as follows: ("heart rate variability" OR "HRV" OR "heart rate" OR "HR" OR "parasympathetic" OR "sympathetic" OR "vagal" OR "vagus" OR "cardiac activity" OR "autonomic activity") AND ("esport*" OR "e-sport*" OR "electronic sport*" OR "electronic gaming" OR "electronic game*" OR "competitive gaming" OR "video gaming" OR "video game*" OR "online gaming" OR "online game*" OR "console gaming" OR "console game*" OR "computer gaming" OR "computer game*" OR "gaming" OR "first person shooter" OR "real time

strategy" OR "MMORPG"). An extensive number of search terms were necessary due to the disparity in terms used within the fields of both esports and HRV literature.

3.3. Eligibility criteria

Studies were selected based on the PICOS criteria (see Table 1).

To further clarify the PICOS criteria some additional information is provided. Following the definition of esports involving casual or organised competitive play (Pedraza-Ramirez et al., 2020) all studies included at minimum recreational competitors, however, novice control groups were accepted (Population). Clinical illness may be physiological or psychological (Population). Studies with participants reported as sedentary or stressed were accepted as were studies that resultantly classified participants as having clinical illness (Population). IGD was the only clinical illness included when specifically considered in an esports context as research has suggested it can be challenging to delineate esports expertise from IGD (Population; Brevers et al., 2020). No restriction was placed on age or sex of participants (Population). Given that esports provide professional or personal development to the player (Pedraza-Ramirez et al., 2020), articles that utilised video games merely as a stressor were excluded as were studies that did not report which esport was investigated (Intervention/Phenomena). In the instance full texts were not accessible to the authors the primary author of the paper was contacted. If the full text was still not available, the paper was excluded (Study design). No restriction was made on publication period (Study design). Exclusion criteria included non-peer reviewed work (i.e., abstracts, conference proceedings, theses, posters), opinion pieces, and review papers due to risk of bias.

3.4. Data collection

Once the initial database search was completed, results were uploaded to Rayyan (online systematic review program) for automatic duplicate removal followed by manual screening. All stages of article screening from this point forth were completed by two independent reviewers. The second reviewer (RB) was proficient in esports research but had limited previous knowledge of HRV. Prior to review, the second reviewer was briefed by the first author and reviewer (MW) to ensure appropriate understanding of HRV and potential confounding factors. Article title and abstract were initially assessed for inclusion followed by assessment of the full text when inclusion criteria were met. Inter-rater reliability was κ = 0.85. Citation and reference searching of included articles was then completed to identify additional studies that met the inclusion criteria. The first author then extracted the following data from each of the included studies; author names and date, participants, protocol, esport(s) used, HRV device and measurement, HRV variables, main findings, and theoretical underpinning (where provided). Theoretical underpinning was identified via manual searching of the text and reference list for citations or demonstrable consideration of recognised HRV theories (i.e., Vagal Tank Theory; Laborde et al., 2018; Neurovisceral Integration Model; Thayer & Lane, 2000; Polyvagal Theory; Porges, 2007) which the authors are very familiar with. Findings of included studies were analysed via narrative synthesis (Siddaway et al.,

2019) due to disparity across all variables of interest. Popay et al. (2006) define narrative synthesis as a process that "relies primarily on the use of words and text to summarise and explain the findings of the synthesis" (p. 5). Narrative synthesis was chosen due to its appropriateness in situations of disparity where traditional methods cannot provide a meaningful summary (Brennan, 2009).

3.5. Risk of bias assessment

Risk of bias within the included studies was assessed individually by two authors (MW & RB) using the Mixed Methods Appraisal Tool (Q. Hong et al., 2018). Both authors had knowledge of esports research and one had particular expertise in HRV who briefed the other prior to assessment. It was determined that the screening questions were not required due to the review inclusion criteria requiring empirical study. Each study was rated based on two standardised questions (e.g., are there clear research questions?) and five criteria appropriate to its category (e.g., quantitative non-randomised; are measurements appropriate regarding both the outcome and intervention or exposure?) with possible responses of "yes", "no", and "can't tell". Studies were not excluded based on low methodological quality as their inclusion is recommended by the original authors (Q. Hong et al., 2018) and this is an area of interest of the present study.

4. Results

4.1. Study selection

Following PRISMA guidelines (Page et al., 2021), a detailed copy of article screening was recorded (Figure 1). In total, 10732 articles were identified from three databases (Web of Science: 1248, PubMed: 634, and EBSCOHost: 8850). 2326 duplicates were removed using automatic detection via Rayyan. Manual screening for duplicates removed an additional 109 articles leaving 8297 articles. Article title and abstract searching resulted in 8244 articles being removed, leaving 53 articles for examination of the full text. Articles of conflict or uncertainty were discussed based on inclusion criteria ($n = 2$) and details of decisions can be seen in Supplementary Material 1. Reasons for rejection at this stage can be seen in Figure 1. This resulted in 45 articles being removed, leaving six articles included. The reference list and citations (via google scholar) of all included papers were then manually searched by the primary reviewer and agreed by the secondary reviewer, retrieving one additional article. Finally, primary authors of included papers were contacted to determine if they had or were aware of any relevant upcoming work, adding zero articles. In total, seven articles were identified for review. For the full PRISMA flow diagram see Figure 1. For the PRISMA checklist see Supplementary Material 2.

4.2. Description of studies

Seven studies were identified that met the inclusion criteria (Figure 1) which were published between 2018 and 2022 in seven different journals. All studies used a quantitative non-randomised study design. HRV was recorded in 236 males and one female totalling 237 participants aged 16–30 years. Of these participants, 60 were classed as professional players, 10 as semi-professional, 14 as university varsity, and 20 as casual gamers. Competitive level of 133 participants were not reported and comprised solely of participants from the IGD studies. From these studies 65 were classed as having IGD and 68 were rank matched controls. League of Legends was the primary esport game of investigation with four studies utilising only this game and a further two including it alongside other titles ($n = 6$). Two studies utilised Overwatch, Rainbow Six Siege, and Counter Strike: Global Offensive and one study used Super Smash Bros, Rocket League, and Call of Duty: Black Ops, respectively. Considering the competitive setting in which the esports were played, four studies utilised online ranked play whereas

Table 1
PICOS model.

Criteria	Response
Population	Healthy esports players or those with IGD
Intervention/ Phenomena	The activity of playing esports
Comparator	HRV
Outcome	Any
Study design	Published studies that investigated HRV in any esports context, were peer reviewed, and available in English.

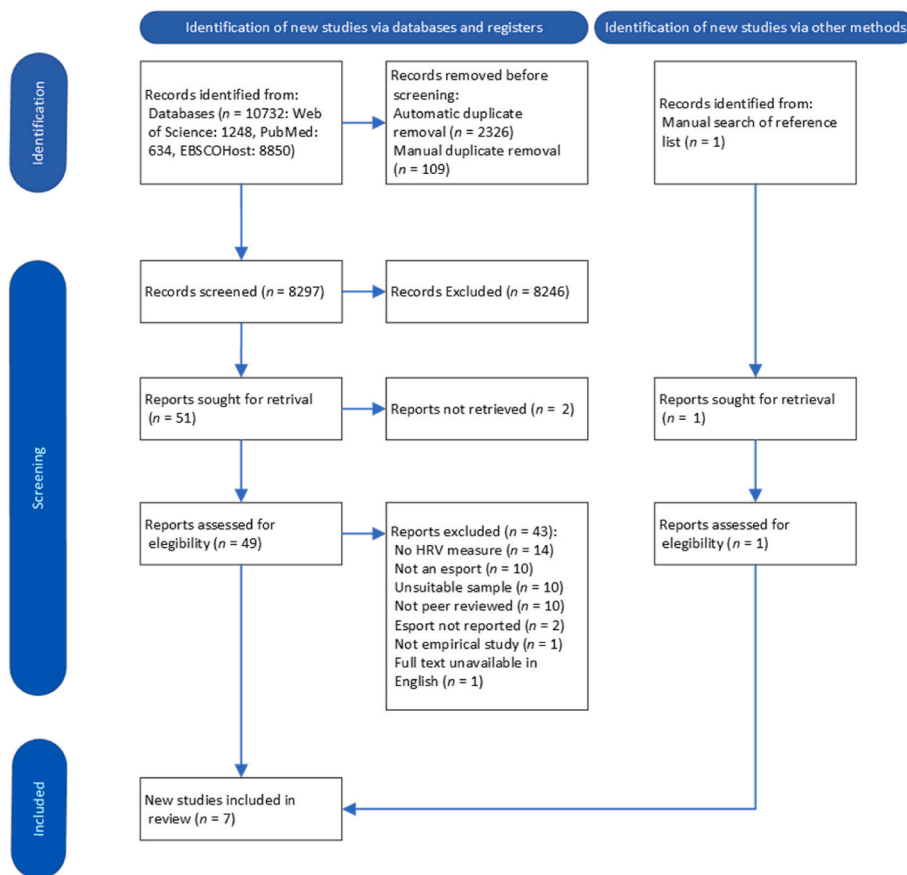*Note.* IGD = Internet Gaming Disorder; HRV = Heart rate variability

Fig. 1. PRISMA flow diagram.

three studies collected data during live tournaments.

4.3. Risk of bias

No conflict between reviewers was found resulting in an inter-rater reliability of $\kappa = 1$. Nearly all studies lacked a comprehensive consideration for confounding variables as seen in Table 2. One study failed to report the specific measures used meaning it was not possible to determine if they were appropriate, and one study failed to report complete outcome data.

4.4. HRV measurement device

To measure HRV, four studies utilised Electrocardiogram (ECG). Two

Table 2
Quantitative non-randomised.

Author	S1	S2	3.1	3.2	3.3	3.4	3.5
Andre et al. (2020)	Y	Y	Y	Y	Y	CT	Y
Bennet et al. (2022)	Y	Y	Y	Y	N	N	Y
Ding et al. (2018)	Y	Y	Y	CT	Y	N	Y
S. J. Hong et al. (2018)	Y	Y	Y	Y	Y	N	Y
Kim et al. (2021)	Y	Y	Y	Y	Y	N	Y
D. Lee et al. (2021)	Y	Y	Y	Y	Y	N	Y
Machado et al. (2022)	Y	Y	Y	Y	Y	N	Y

Note. Standardised questions: S1. Are there clear research questions? S2. Do the collected data allow to address the research question? Study design specific questions: 3.1: Are the participants representative of the target population? 3.2: Are measurements appropriate regarding both the outcome and intervention (or exposure)? 3.3: Are there complete outcome data? 3.4: Are the confounders accounted for in the design and analysis? 3.5: During the study period, is the intervention administered (or exposure occurred) as intended?

of these studies used the three lead MP150 Biopac, a single study used a two lead QEEG-64FX, and a single study used a one lead Hexoskin smart shirt. The remaining three studies used different conductance sensors; Polar H10 chest strap, Polar RS800cx chest strap and watch, and Bio-harness chest harness.

4.5. HRV parameters reported

The most used vmHRV measure was RMSSD ($n = 5$), followed by HFms^2 ($n = 2$) and pNN50 ($n = 1$). Considering HRV measures from the time domain, standard deviation of all normal sinus beats (SDNN; $n = 4$) was used most frequently. This was followed by R–R interval ($n = 3$), standard deviation of all sinus beats including abnormal or false beats (SDRR; $n = 1$), natural log applied to the RMSSD (LnRMSSD; $n = 1$), NN interval ($n = 1$), mean NN intervals ($n = 1$), standard deviation of differences between adjacent NN intervals (SDSD; $n = 1$), and number of pairs of successive NN intervals that differed by more than 50 ms (NN50; $n = 1$). Of the HRV measures from the frequency domain, the most used was low frequencies/high frequencies ratio (LF/HF; $n = 4$), followed by absolute power of low frequencies (LFms^2; $n = 2$), relative power of low frequencies in normalised units (LFnu; $n = 2$), natural log applied to low frequencies (LnLF; $n = 2$), relative power of high frequencies in normalised units (HFnu; $n = 2$), natural log applied to high frequencies (LnHF; $n = 2$), pNN50 count divided by the total number of all NN intervals (pNNI50; $n = 1$), the percentage of adjacent NN intervals that differ by more than 20 ms divided by the total number of all NN intervals (pNNI20; $n = 1$), absolute power of very low frequencies (VLFms^2; $n = 1$), and total power ($n = 1$). It should be noted that one study failed to report the specific HRV parameters used and another did not report results for all proposed parameters (see Table 3).

Table 3
Overview of included papers investigating HRV in esports.

Study	Participants	Esport(s)	Protocol	HRV variables	Theory	Methodological guideline	Findings
Andre et al. (2020)	14 male university players (*M* age = 19.8, *SD* 1.0 years)	Overwatch, Super Smash Bros, Rocket League, CS:GO, COD: Black Ops, League of Legends, Rainbow Six Siege	Device: Polar H10 (R–R interval) Measurement: 15–25 min pre-game for 5 min Whole game Post-game for 5 min Setting: Live university tournament Single game	**Time** RR (ms)* RMSSD (ms) LnRMSSD (ms) SDNN (ms) NN50 (ms) **Frequency** LF/HF (ms^2) LF (ms^2)* HF (ms^2)*	N/A	N/A	Significant change of RR over time. RR decreased from pre to in-game then increased from in-game to post-game (not returning to pre-game levels). LF(ms^2) showed significant decrease from pre to post-game. HF(ms^2) showed significant decrease from pre to post-game.
Bennet et al. (2022)	Male 18–30 years, competitive players (competed in the last year) Sample size unclear	League of Legends, Overwatch	Device: Hexoskin smart shirt (1 lead ECG) Measurement: Whole game minute values Setting: Live competition 1.5–2hr session	**Time** SDRR (ms) NN (ms) RR (ms)	N/A	Malik (1996)	SDRR distinguished between play and rest at a team level. Significant differences were observed between winning and losing teams (values not reported, unable to determine direction or significance of reported measures).
Ding et al. (2018)	10 male professionals (*M* age 21, Range 18–24 years) 10 male semi-professionals (*M* age 18yrs, range 15–24 years) One female and 19 male casual gamers (*M* age 20yrs, range 19–21 years)	League of Legends	Device: Bioharness 3 (R–R interval) Measurement: First 5 min, middle 5 min, and final 5 min of each game Setting: Online ranked play 1 or 2 games in teams of 5 Instructed to keep verbal communication to a minimum.	**Time** Specific HRV measures unclear	N/A	N/A	Significantly higher HRV was reported in professional and semi-professional groups than casual gamers during the end phase of gameplay.
S. J. Hong et al. (2018)	21 males with internet gaming disorder (Y-IAT >50; *M age* = 22.3, *SD* 2.9 years) 27 rank matched controls (Y-IAT >50; *M* age = 21.8, *SD* 2.8 years)	League of Legends	Device: MP150 Biopac (3 lead ECG) Measurement: 5 min resting 5 min during high/low attention instances in game (identified via game log post game) 5 min post Setting: Online play (unknown type) 3 games with 5 min rest	**Time** SDNN (ms), RMSSD (ms)* **Frequency** LnLF (UNS), LnHF (UNS)* LF/HF (ms^2)	N/A	Laborde et al. (2017)	Young males with IGD showed significantly reduced LnHF(uns) during periods of high attention and the final 5 min when compared to baseline. Severity of IGD predicted the reduction in LnHF(uns). RMSSD showed a significant interaction between game period and group. Trends towards reductions in RMSSD for participants with IGD during periods of high attention were noted but not significant.
Kim et al. (2021)	23 male students (*M* age = 23, *SD* 3 years) 11 with IGD (CIUS >2.5 & IAT >50) 12 without IGD (CIUS <1.5 & IAT<40)	League of Legends	Device: Auxiliary channel of QEEG-64FX (2 lead ECG) Measurement: In game for 30s, 60s, 90s, and 120s post "killed event" or "killing event" Setting: Online play 1 normal game for familiarisation then 2 ranked games Blind to inclusion in IGD or control group	**Time** Mean NNI (ms) SSDN (ms) SDSD (ms)** pNNI50 (%) pNNI20 (%)* RMSSD (ms)** **Frequency** 30s LF (ms^2)* 60s LF (ms^2)** HF (ms^2) VLF (ms^2) LF/HF (ms^2) LFnu HFnu Total power (ms^2)**	N/A	Malik (1996)	Significant reduction in, pNNI20, LF (ms^2), RMSSD, SDSD, and Total Power was observed between individuals with IGD and healthy participants in the 30s post "killed event". Logistic regression suggested pNNI20, RMSSD, and LF(ms^2) best reflected the difference in stress response for a window of 30 s after a "being killed" event. Area Under the Curve calculations revealed discriminating power between 0.654 and 0.677. A significant reduction in LF(ms^2) was observed between individuals with IGD and healthy participants in the 60s post "killed event".
D. Lee et al. (2021)	33 gold tier males with IGD (IAT >50; *M* age 23.1, *SD* 2.8 years) 29 gold tier <50; *M age* 22.0, *SD* 2.8 years)	League of Legends	Device: MP150 Biopac (3 lead ECG) Measurement: 5 min resting First 5 min of gameplay Setting: Online play (unknown type)	**Time** RMSSD (ms) SDNN (ms) **Frequency** LnLF (UNS) LnHF (UNS)*	N/A	Laborde et al. (2017)	Baseline and game related HRV were not significantly different between groups. Game related reactivity of LnHF(uns) was significantly different between groups with IGD participants displaying decreased LnHF(uns) after starting gaming.

Table 3 (*continued*)

Study	Participants	Esport(s)	Protocol	HRV variables	Theory	Methodological guideline	Findings
Machado et al. (2022)	50 Brazilian professional male players (*M* age 24.98, *SD* 2.59 years) 25 Victory group 25 defeat group	CS:GO, Rainbow Six Siege	Device: Polar RS800cx (R–R interval) Measurement: 10 min recording 60 & 30 min pre-game 10 min post game Setting: Decisive live games in international competitions 10 teams of 5	**Time** RR (ms)* SDNN (ms)* pNN50 (ms)* RMSSD (ms)* **Frequency** LF (n.u)* HF (n.u.)* LF/HF (ms^2)*	N/A	Laborde et al. (2017)	Reduction in LnHF(uns) was significantly correlated with the severity of IGD. Post-game RR, SDNN, RMSSD, pNN50, and HF(n.u) were significantly higher in the victory group than defeat group. Post-game LF(n.u) and LF/HF were significantly lower in the victory group than defeat group. No difference was observed at 30- or 60-min pre-game between victory and defeat groups.

Note. SDNN = Standard deviation of all normal sinus beats; SDRR = Standard deviation of all sinus beats (including abnormal or false beats); SDSD = Standard deviation of differences between adjacent NN intervals; RMSSD = Root mean square of successive differences between adjacent NN intervals; LnRMSSD = Natural log applied to the RMSSD; NN50 = Number of pairs of successive NN intervals that differed by more than 50 ms; pNN50 = The percentage of adjacent NN intervals that differ by more than 50 ms; Mean NNI = Mean NN intervals; pNNI50 = pNN50 count divided by the total number of all NN intervals; pNNI20 = The percentage of adjacent NN intervals that differ by more than 20 ms divided by the total number of all NN intervals; LF = Low frequencies; HF = High frequencies LnLF = Natural log applied to low frequencies; LnHF = Natural log applied to high frequencies; ms = Millisecond; ms^2 = Millisecond squared; nu = Normalised units; UNS = Unit not specified; CS:GO = Counter Strike: Global Offensive; COD: Black Ops = Call of Duty: Black Ops.

* Significant difference $p < 0.05$.
** Significant difference $p < 0.1$.

4.6. Timing of measurement

The most common timing of measurement was in game ($n = 6$). This varied in duration between 5-min segments during times of interest ($n = 3$; initial 5 min;periods of high attention; initial 5 min, middle 5 min, and final 5 min), the entire game duration ($n = 2$), and 30s, 60s, 90s and 120s measures at instances of kill or killed ($n = 1$; referring to when the players in game avatar kills another players avatar or their avatar is killed). A pre-game measure was the second most utilised ($n = 4$) with the most common duration of 5 min ($n = 3$) taken 15–25 min pre-game ($n = 1$) to immediately pre-game ($n = 2$). A single study took a 10-min resting measure 60 min and 30 min pre-game. Finally, post-game measures were the least used time point ($n = 3$), most commonly 5 min in duration immediately post-game ($n = 2$) or 10 min duration 10 min post-game ($n = 1$). Detailed breakdown of measurement timings can be seen in Table 3.

4.7. Theoretical underpinning and methodological recommendations

No study explicitly demonstrated theoretical underpinning within their methodological design or aims. Two studies (S. J. Hong et al., 2018; D. Lee et al., 2021) referred to the Neurovisceral Integration Model (Thayer & Lane, 2009) and specifically referred to the use of vmHRV to index executive control, however, this was primarily within the discussion and specific consideration of vmHRV was not evidenced in the methodology. The use of methodological recommendations was common ($n = 5$), with those by Laborde et al. (2017) most frequently used ($n = 3$) followed by the recommendations of Malik (1996; $n = 2$).

4.8. Narrative synthesis

The aim of the present study was to systematically review how HRV has been utilised within esports research. Two key applications including stress response and IGD emerged and are discussed further.

4.8.1. Stress response (n = 4)

HRV was frequently used to investigate stress within esports. While this is a common association due to the involvement of the autonomic nervous system (Laborde et al., 2018), it should be noted there are several limitations which will be addressed in the discussion. Ding et al. (2018) suggest HRV (measures not specified) can be used to differentiate expertise during the end phase of gameplay. They observed increased

HRV in professional and semi-professional players compared to casual gamers in the final 5 min. Higher HRV was attributed by the authors to the professionals' ability to manage in-game stressors such as the breakdown of structured play often found in the final 5 min (Ding et al., 2018). A stress response has additionally been observed during live competition with HRV (RR) significantly reducing in-game compared to pre- and post-game. When combined with HR data this further suggests a metabolic demand typical of vigorous aerobic activity rather than sedentary activity (Andre et al., 2020). The authors also observed a significant reduction in vmHRV (HFms^2) from pre-to post-game suggesting a reduction in parasympathetic control (Andre et al., 2020). Greater parasympathetic activation post-game has been shown to distinguish victory groups over those defeated via increased RMSSD, pNN50 (vmHRV), RR, SDNN, HFnu (HRV), and decreased LFnu and LF/HF (HRV; Machado et al., 2022). It should be noted that no significant differences in these measures were observed between victory and defeat groups pre-game (Machado et al., 2022). Although there is clearly support for the use of HRV, Bennet et al. (2022) warn it is unlikely to be useful as a generalisable assessment of performance without a high level of context. Bennet et al. (2022) found high individual HRV variation which was speculated to be due to the differing roles and situations faced by players within the team. Due to high variation in the timing and measurement of HRV, results tentatively indicate a reduction in HRV during stressful situations (see Table 3).

4.8.2. Internet Gaming Disorder (n = 3)

HRV has been shown to consistently differentiate individuals with IGD during League of Legends gameplay (S. J. Hong et al., 2018; Kim et al., 2021; D. Lee et al., 2021). This was commonly associated with a reduction in LnHF (uns) and consequently a lower HRV (S. J. Hong et al., 2018; D. Lee et al., 2021). Findings by Kim et al. (2021) further suggest individuals with IGD are characterised by a differing stress response in the 30s window following a "being killed" event. RMSSD (vmHRV), LFms^2, and pNNI20 (HRV) showed significant differences between IGD participants and controls, however, Area Under the Curve calculations following regression suggest less than accurate prediction. No significant response was seen when considering a period of 60s, 90s, or 120s following "being killed". S. J. Hong et al. (2018) observed a reduction in LnHF (uns; HRV) during periods of high stress, specifically in the final 5 min of gameplay which could be predicted by severity of IGD. They also identified significant longitudinal changes in RMSSD (vmHRV) and LnHF (uns; HRV) during gameplay, however, while trends towards

reduction in RMSSD (vmHRV) during high stress situations (final 5 min) were also observed, these were non-significant (S. J. Hong et al., 2018). No study identified significant differences between IGD and control participants at baseline. Although variation in timing and measurement of HRV was observed, results indicate individuals with IGD may have different responses to esports and associated in-game stimuli to healthy participants.

5. Discussion

The aim of the present study was to systematically review the utilisation of HRV in esports research. Seven studies were identified that were distinct in both content and methodology. The review prioritised vmHRV due to its clear physiological origins and theoretical underpinning as established by Laborde et al. (2017, 2018) and Thayer and Lane (2009). However, caution was exercised while acknowledging other measures (where appropriate). Our review identified two primary research areas; stress response and IGD.

5.1. Stress response

Esports generates a vmHRV (HFms^2) response in participants even though the activity itself is sedentary in nature (Andre et al., 2020). Previous research has suggested esports players face a multitude of stressors comparable to that of traditional athletes (Leis & Lautenbach, 2020; Poulus et al., 2020; Smith et al., 2019), therefore, necessitating a physiological response (Bohus et al., 1987). The exact relationship of the response requires further investigation, however, several observations can be made. No differences in baseline vmHRV (pNN50, RMSSD) between victory and defeat groups were reported (Machado et al., 2022). However, significantly higher vmHRV (pNN50, RMSSD) of the victory group post-game implies either lower self-regulatory demand or faster recovery (Laborde et al., 2018; Machado et al., 2022). Without specific in-game data, it is not possible to identify cause and effect, however, the findings of Ding et al. (2018) allow for some speculation. Professional and semi-professional players demonstrated greater HRV (measurement not reported) in the final 5 min compared to casual gamers; which is considered as the most stressful period of gameplay in League of Legends (Ding et al., 2018; S. J. Hong et al., 2018). Therefore, players with greater expertise may be able to deal with in-game stressors more effectively and incur a lower self-regulatory demand. It can therefore tentatively be suggested that higher vmHRV indicates increased self-regulation and consequently performance.

One study suggests that HRV (SDRR, NN, RR) may be unsuitable as a measure of performance in esports (Bennett et al., 2022) due to high individual variation. Performance is currently a contentious term within esports due to the uncertainty surrounding what this may involve for different player roles (see Sharpe et al., 2023). There is also a common misconception within HRV research that HRV can directly measure performance. To better encompass what vmHRV can measure, use of the term self-regulation is encouraged, which may in turn relate to either action, process, or outcome performance (if performance relies on cardiac vagal activity; see Mosley & Laborde, 2022; Sharpe et al., 2023). While Bennet et al. (2022) refer to individual variation, the term individual difference may be more appropriate. Due to the number of potentially confounding variables affecting vmHRV and pre-existing individual differences (i.e., age, gender), it is typically recommended that investigation is completed using a within-subjects design (Laborde et al., 2017; Quintana & Heathers, 2014). While phenomena such as signal averaging may allow researchers to identify trends across a team (Trimble, 1968), caution should be advised due to inherent individual differences questioning the meaning of such measures (Laborde et al., 2017). Consequently, researchers and practitioners harnessing vmHRV as an indicator of self-regulatory performance should compare within-player differences with a high level of contextual information.

5.2. Internet Gaming Disorder

All studies investigating IGD found significant differences between in-game HRV (LnHFuns, PNNI20, LFms^2) of IGD participants and individuals without IGD (S. J. Hong et al., 2018; Kim et al., 2021; D. Lee et al., 2021). However, baseline and post-game vmHRV (RMSSD, HFms^2) showed no significant differences between individuals with and without IGD (S. J. Hong et al., 2018; D. Lee et al., 2021). Results would therefore imply HRV could potentially be used to differentiate individuals in-game. Both S. J. Hong et al. (2018) and D. Lee et al. (2021) suggest the severity of IGD predicted a reduction in LnHF (uns). It should be noted that due to the authors not reporting the unit of measurement prior to transformation it is unknown if this originated from absolute power (HFms^2) which is vagally mediated or another derivative (i.e., HF % or HFnu). Consequently, the conclusions that can be drawn from these results are severely limited. It may be speculated that reduced vmHRV could be caused by a reduction in executive control during gameplay (S. J. Hong et al., 2018; D. Lee et al., 2021; Thayer & Lane, 2000). Executive control pertains to the individual's ability to regulate goal directed thoughts and behaviour (Suchy, 2009), therefore, as individuals with IGD have addictive tendencies (American Psychiatric Association, 2013) a reduction in goal directed behaviour may also be observed (e.g., habitual play without purpose). Growing evidence has shown links between vmHRV (HFms^2) and executive function (Forte et al., 2021; Williams et al., 2016), however, further research is required to support a relationship between vmHRV and the severity of IGD.

Initial research specifically investigating the quantification of IGD via HRV has shown limited results. RMSSD (vmHRV), LFms^2, and PNNI20 (HRV) were suggested to best differentiate individuals with IGD from healthy participants in the 30s following their in-game avatar "being killed" (Kim et al., 2021). While these variables were seen to provide the best fit, the authors concede they were not sensitive enough to act as a predictor of IGD (Kim et al., 2021). Of note in this instance, the vmHRV measures (RMSSD, HFms^2) were not significantly different between individuals with IGD or healthy participants at any time point in game (Kim et al., 2021). These findings would potentially conflict with those of S. J. Hong et al. (2018), however, it is unclear if a period of high attention would constitute the time prior to, following, or encompassing in-game death. It is therefore challenging to compare these findings further. In summary, the current literature investigating vmHRV in individuals with IGD is mixed. A lack of focus on vmHRV variables along with inconsistent measurement means further research is required to synthesise meaningful insight.

5.3. Common limitations

Whilst all papers included in this systematic review have merit and add to the sparse literature base, there are several common limitations. It should be noted that these limitations are prevalent across the entire sport and exercise psychology literature base (Mosley & Laborde, 2022) and not confined to esports alone.

5.3.1. Theoretical underpinning

Of the seven included studies, none showed clear consideration of a recognised vmHRV theory within their aims or methodological design. Two made direct reference to a recognised theory (S. J. Hong et al., 2018; D. Lee et al., 2021) and one made indirect reference (Machado et al., 2022). The use of theory ensures robust hypothesis testing and provides defined direction for research (Muthukrishna & Henrich, 2019), which is particularly important in emerging areas such as esports. Theory is needed to guide HRV research towards using established means to examine self-regulation and away from examining stress per se. The appraisal of stress is a complex and multifaceted endeavour due to the influence of multiple systems including the parasympathetic and sympathetic nervous systems (Bohus et al., 1987). While possible to index cardiac vagal activity of the parasympathetic system through

vmHRV, the sympathetic system requires impedance cardiography and the measurement of the pre-ejection period to be considered in addition to electrocardiography (Sherwood et al., 1990). Therefore, using vmHRV alone is unsuitable for achieving a full picture of stress. Underpinning theory provides scope for readers, researchers, and practitioners to synthesise information in a coherent manner. Due to the lack of application of theory in the current review, the ability to draw meaningful and insightful conclusions was limited. It is highly recommended that future research and practice is underpinned by theory to provide a guiding framework to enable accurate hypothesis testing and player support.

5.3.2. HRV measurement

Five of the seven studies included in the present review employed the methodological guidelines of either Laborde et al. (2017) or Malik (1996) indicating a promising trend towards adherence to established guidelines. However, further consideration is required in the selection and application of these guidelines. Two studies (Bennett et al., 2022; Kim et al., 2021) utilised the somewhat outdated recommendations of Malik (1996), which suggest the LF/HF ratio is an indicator of sympathovagal balance. Extensive research including numerous blockade studies (Heathers, 2012; Martelli et al., 2014; Reyes del Paso et al., 2013) has since shown LF is a mixture of sympathetic, parasympathetic, and baroreflex activity, as such the measure should be avoided (Ackermann et al., 2021; Billman, 2013; Martelli et al., 2014; Mosley & Laborde, 2022). In contrast, contemporary guidelines by Laborde et al. (2017) were acknowledged by three studies (S. J. Hong et al., 2018; D. Lee et al., 2021; Machado et al., 2022), but adherence to these guidelines were not strict. Laborde et al. (2017) specifically advocate the use of vmHRV measures and comprehensive pre-screening of confounding variables. Variables such as sleep and caffeine may be of particular interest to researchers and practitioners in esports due to the tendency for players to engage in poor quality delayed sleep patterns (S. Lee et al., 2021; Smith et al., 2022) and habitually consume high caffeine beverages (Shulze et al., 2021; Thomas et al., 2019). The pre-screening checklist and comprehensive list of confounding variables can be found in the supplementary files of Laborde et al. (2017).

There is also a need to report HRV measurement units. HF can be measured in multiple ways, including absolute power of high frequencies (ms^2), percentage power of high frequencies (%), and normalised units of high frequencies (nu). However, only absolute power of high frequencies is considered to capture the vagally mediated aspect of HRV (when breathing is comprised between 9 and 24 cycles per minute) as other calculations involve other parameters such as LF, meaning clear physiological origin cannot be determined (Mosley & Laborde, 2022). Therefore, measures neglecting such parameters severely compromise one's ability to infer valid conclusions from HRV data. For this reason, it can be strongly recommended in future esports research and beyond that vmHRV measures (RMSSD, PNN50, $HFms^2$) should be prioritised due to their ability to infer causality via their physiological origins.

5.4. Limitations of the review

While our review advances understanding, it is important to acknowledge its limitations. Our review may have been limited due to the current lack of a globally agreed definition of esports. The definition proposed by Pedraza-Ramirez et al. (2020) was used although it is acknowledged that some scholars may challenge this. The prescriptive list of esports caused the exclusion of otherwise potentially eligible studies utilising popular games (e.g., Gran Turismo: Subahni et al., 2012; Bomberman: Chanel et al., 2012), however, it may be argued the included games reflect the current state of organised esports. Notwithstanding, Pedraza-Ramirez et al.'s (2020) definition is also arguably the most widely supported definition to date which has been used in a previous systematic review (Leis & Lautenbach, 2020). Originating from a systematic review itself, it offers potentially the most comprehensive

and robust definition proposed thus far. Due to lack of congruence in the measurement of HRV via the variables used, timing of collection, and duration of collection, the present review was also limited in its ability to synthesise findings of included studies. The application of theory (Laborde et al., 2018) to underpin our synthesis provided structure and allowed limited interpretation of findings via vmHRV measures. The incongruence seen within the reviewed studies reinforces the need for our systematic review at this early stage within the research to avoid repetition of the same mistakes identified within the wider sport and exercise psychology literature (Mosley & Laborde, 2022). It is acknowledged that the perfect inter-rater reliability observed for risk of bias assessment is uncommon. It should be noted that while the first reviewer briefed the second on HRV, this briefing occurred prior to assessment of included text for the systematic review (where disagreement was observed) which informed the risk of bias. Consequently, perfect agreement was likely due to the small number of included studies and their inherent limitations.

6. Conclusion

The aim of the present study was to systematically review the use of HRV in esports research. Although the current evidence base is limited, the findings suggest HRV has been utilised for investigating stress response (self-regulation) and IGD in esports. However, a major limitation that emerged from the review was a lack of theoretical and methodological underpinning in HRV research in esports, which severely limits the synthesis and interpretation of results. HRV research in esports is following the same path as the wider HRV literature (Mosley & Laborde, 2022), and it is hoped this review serves as a timely intervention to steer esports researchers away from this path. Without the use of appropriate theory and robust methodology, we are currently seeing chaos in the brickyard (Forscher, 1963). To draw upon Forscher's metaphor, until solid foundations are built, the synthesis and true application of HRV in esports will be limited. We urge HRV researchers and practitioners in esports and beyond to use underpinning theory and methodology to strengthen methodological design and data interpretation. In conclusion, while HRV and particularly vmHRV hold great promise, further investigation is necessary before making robust recommendations regarding the use of HRV in esports research and practice. To advance research and build solid foundations for practice, we provide four key methodological considerations and four areas of potential future research interest below.

6.1. Methodological considerations

1. Appropriate theory

We strongly recommend that researchers and practitioners underpin future work with contemporary theories such as the Vagal Tank Theory (Laborde et al., 2018). The three R's proposed in the Vagal Tank Theory provide clear recommendations on the unit (RMSSD, pNN50, $HFms^2$) and timing (rest, reactivity, and recovery) of measurement. Standardising the unit and timing of measurement may allow future work to be synthesised leading to greater collective impact.

2. Methodological guidelines

Greater consideration needs to be placed on the pre-screening of potential confounding factors and stricter adherence to guidance is necessary. While multiple guidelines are available, those of Laborde et al. (2017) which include a comprehensive pre-screening checklist are recommended.

3. Defining esports

Echoing the recommendations of Leis and Lautenbach (2020),

researchers should consider that not all video games are esports. We direct readers to the definition proposed by Pedraza-Ramirez et al. (2020) which provides a comprehensive list of included esports.

7. Measurement device

Consideration should be given to the type of HRV measurement device used. Only ECG allow for manual correction of artifacts, therefore, Holter ECG are recommended and should be considered the gold standard (Hinde et al., 2021). Some conductance sensors (i.e., Polar H10) have shown similar signal quality in low to moderate activity (Gilgen-Ammann et al., 2019), however, further esports specific validation is required due to differences in recording position and associated movement (Dobbs et al., 2019). Photoplethysmography is considered inaccurate during stressful situations or when motion increases (Georgiou et al., 2018; Hinde et al., 2021; Schäfer & Vagedes, 2013) and given it is commonly taken from the wrist or finger, it may be inappropriate in esports due to interference with participants action performance.

7.1. Future research

1. Participants

HRV research in esports has typically focused on males in League of Legends. Different games have varying demands based on the structure and duration of play. Precision is therefore required when reporting findings to differentiate and/or generalise where appropriate. Given gender can influence HRV (Kuo et al., 1999), there is a clear under-representation of females in HRV research in esports. Therefore, we encourage researchers to harness the broad range of sample demographic characteristics and esport titles to advance our understanding.

2. Self-regulation

Future research may benefit from examining the mechanisms underpinning the physiological self-regulatory response. Although academics and practitioners have a preliminary understanding of cognitive self-regulation strategies used by esports players, further research should consider the physiological facet of self-regulation.

3. IGD

To advance our understanding future research should investigate the potential of vmHRV to predict severity of IGD. Researchers are encouraged to consider the role of executive functioning and take particular interest in the in-game reactivity period.

8. Psychological tools

Esports players typically have significantly lower use of self-regulatory tools such as self-talk, goal setting, imagery, and relaxation techniques when compared to traditional sports, however, this is potentially due to their lack of training in such techniques (Trotter et al., 2021). Future research should consider investigating the application of such techniques and the potential of vmHRV to index their effectiveness.

Author note

We have no known conflict of interest to disclose.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.psychsport.2023.102495.

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