Heart Rate Variability as a Measure to Identify Autonomic Dysfunction and Mental Health Disorders in Public Safety Personnel

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Abstract

Introduction. Unresolved trauma from critical incident exposures may lead to autonomic dysfunction and mental health disorders in public safety personnel (PSP). Heart rate variability (HRV) is a highly sensitive measure that can be used alongside psychological assessments to identify early warning signs of autonomic dysfunction that may be an early detector of worsened mental health.

Objectives. The two primary objectives of this project were to: 1) critically appraise the literature involving HRV assessment in identifying mental health disorders in PSP based on its scientific rigor, and 2) develop a knowledge translation (KT) tool in the form of an infographic to guide HRV measurment and interpretation as a surrogate indice of autonomic function.

Method. To address objective 1, methods developed by Arksey and O'Malley (2005) were adapted to conduct a scoping review on studies that used HRV to assess mental health and/or autonomic function in PSP. A quality appraisal (MacDermid et al., 2014) and a physiological HRV checklist (Catai et al., 2020) were combined into a hybrid critical appraisal tool to assess scientific merit of all studies. To address objective 2, high quality findings of the scoping review and the physiological HRV checklist (Catai et al., 2020) were used to develop an HRV measurement guideline infographic.

Results. Objective 1: The scoping review identified a primary theme that regardless of physiological adherence to scientific merit, a decreased HRV is linked to worsened mental health in 84% of studies (n=16). Three studies reported mixed findings of conflicting results regarding HRV being correlated to mental health disorders, demonstrating significance in some but not all areas of the studies. The subtheme was that despite many critical confounding factors not being controlled for, HRV was still linked to mental health in all studies (n=19). Objective 2: Using

KT, an infographic tool was developed for applied researchers who use HRV as a method of measuring autonomic function and/or mental health in applied settings such as with PSP. The tool outlined baseline testing standardization, optimal study design, devices and analysis type, and interpretation of findings.

Discussion. The key findings of the scoping review were that worsened mental health and/or autonomic function may be identified by a lowered HRV as a supportive measure to psychological assessments, and based on current quality appraisal scores, the majority of studies are of medium quality. Thus, there is a need for KT implementation to improve accuracy of HRV measurement protocols in the field. Some of the deficits in HRV measurement procedures identified included lack of controlling for environmental factors such as participant distractions, behavioural factors such as physical activity and nutrition guidelines prior to testing, and conducting a standardized baseline measurement. Misuse of the HRV alone in predicting mental health conditions may lead to errors such as a false positive or worse, a missed negative if the measure failed to detect declining mental health in a PSP. Therefore, when following best practice guidelines, HRV may be a valid physiological assessment tool alongside psychological assessments that can help with the early identification of autonomic dysfunction in PSP.

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Chapter 1: LITERATURE REVIEW

Public safety personnel (PSP) including paramedics, police officers, firefighters, and military personnel, provide crucial services to support the health of citizens and protect the safety of communities while being exposed to events that impose high physical and psychological demands (Carleton et al., 2018). While doing so, PSP face extreme situations of stress due to the nature of their work, responsibility for safety, and social expectations (Ricciardelli et al., 2020b). A critical incident exposure (CIE) is defined as an unusually strong emotional reaction experienced by a PSP to an event (Halpern et al., 2012). A CIE can occur by witnessing a gruesome accident or death, and can result in psychological and physiological effects capable of impairing function (Halpern et al., 2012). If the impacts of CIE are left unresolved they can lead to autonomic dysfunction and mental health disorders including post-traumatic stress disorder (PTSD), depression, anxiety, and substance use disorder (Carleton et al., 2018). Various methods are used to assess impacts of CIE on mental health which is defined as a state of well-being where one can cope with the normal stresses of life and work productively to make a contribution to their community (Galderisi et al., 2015). The psychological assessments collected via interviews, self-report surveys, and questionnaires are standardized and validated to detect mental health, but mental health disorders among PSP are under-reported and some data remains unreliable when these techniques are used as stand-alone tools (Carleton et al., 2018). This is primarily due to self-report bias which limits the accuracy of responses from PSP (Carleton et al., 2018).

An applicable method of assessing physiological signs of stress involves measuring autonomic function indirectly through heart rate variability (HRV). This technique considers the variation in time between consecutive heartbeats, and provides a quantifiable avenue for early identification of changes in the autonomic nervous system function (Boissoneault et al., 2019; Marshall & Garakani, 2002). Interpretation of HRV as a metric is dependent on its use following methodological guidelines outlined in a checklist by Catai et al., (2020) found in Appendix A. Primary methodological concerns with HRV assessment is the validity of data collection parameters; such as adhering to strict protocols (i.e., physiological and environmental controls) and data analysis misinterpretations in data collected using time and/or frequency domain (Board et al., 2016; Hayano & Yuda, 2019). The intent of this initial literature review is to summarize what is understood about autonomic function in PSP who experience mental health disorders resulting from their high levels of CIE as a precursor to the proposed in-depth scoping review. The following sections will also attempt to characterize the link between CIE and mental health as explored through the utilization of HRV as an early detection method.

1.1 Critical Incidence Exposure and Mental Health

Mental health disorders are of concern in PSP, and are under reported (Carleton et al., 2018). Based on self-report, nearly half (44.5%) of PSP screened positive for mental health disorders, which is four times greater than the general population and is linked to injury, functional decline, and personal and family issues (Shields et al., 2021). The Canadian Public Safety Committee found that estimated reports of PSP affected by mental disorders (10-35%) were underestimated, potentiating stigma and creating barriers for care seeking (Carleton et al., 2018; Shields et al., 2021). First responders are exposed to violent and traumatic emergency scenes that may involve witnessing injuries, deaths, and threats to safety or life which has negative effects on emotional control and mental health (Kehl et al., 2014). These conditions increase the risk of psychological dysfunction resulting in a greater likelihood of developing

PTSD, depression, anxiety, cognitive impairment, vulnerability to alcohol use disorder, and autonomic impairments characterized by autonomic dysfunction (Fonkoue et al., 2020). Post-traumatic stress disorder is marked by re-experiencing an event through distressing recollections, emotional numbness, avoidance of reminders of the trauma, and increased arousal (Koresh et al., 2016). Co-morbidities often arise in individuals with PTSD as physiological triggers can cause psychological episodes, and vice versa (Carleton et al., 2018). Over time, PTSD becomes more strongly associated with multiple medical disorders, but there is not a corresponding increase in use of medical services in veterans, indicating underutilization of medical care (Possemato, Wade, Andersen, & Ouimette, 2010). Early signs of mental health disorders are quantified by self-report psychological assessments; however, PSP are underreporting, suggesting that these tools used to assess mental health must be supported by alternative objective measures (Shields et al., 2021). With early detection and diagnosis of mental health disorders in PSP comes earlier access to evidence-based treatments to reduce disability severity and improve health outcomes. As a physiological measure that can be quantified over time, HRV has been proposed as a tangible way to improve early detection of autonomic dysfunction associated with mental health disorders. Individuals under high chronic stress demonstrate lower HRV suggesting altered sympathetic and parasympathetic activity among other physiological implications (Chalmers et al., 2014).

1.2 Physiological Impacts of Critical Incidence Exposure

The autonomic nervous system (ANS) is responsible for maintaining physiological homeostasis as it controls involuntary functions responsible for homeostatic mechanisms including breathing, heart rate (HR), blood pressure, core temperature, stress responses, and blood flow (Sanchez-Manso et al., 2020). Individuals with PTSD linked to CIE experience acute and lingering physiological burdens including sympathetic hyperactivity, reduced baroreceptor sensitivity, and consequent reductions to HRV (Brudey et al., 2015; Fonkoue et al., 2020). This chronic illness is prevalent in upwards of 20% of post 9/11 military veterans who also have a 59% higher chance of developing hypertension (Fonkoue et al., 2020). The majority of evidence supports an association between PTSD with compromised immune function and heightened inflammation (Brudey et al., 2015). Inflammation can be a product of poor lifestyle behaviors and negative coping mechanisms as habits such as sedentary activity, drinking and smoking increases inflammation whereas exercise reduces it. Hence, PSP with CIE induced PTSD who do not exercise regularly, or drink and/or smoke to excess are more prone to dysregulation of the ANS (Brudey et al., 2015). By measuring autonomic function via HRV, a measure that fluctuates as result of sedentary lifestyles, smoking, and drinking, it may improve early detection of chronic stress in PSP resulting from cumulative CIE trauma when combined with other assessments of mental health.

1.3 Stress Response in Public Safety Personnel

Stress is the body's reaction to any change that requires an adjustment or response physically or psychologically (Selye, 1976). The stress response in humans is both physiological and psychological; and is directly related to autonomic function as psychological stress has a physiological response. Psychological stressors are situations interpreted as negative or threatening that have a physiological response. Physiological stressors perturb homeostasis in the body via exercise, hydration, extreme temperatures, or physical pain and can trigger a psychological response. Distress is a situation of threatened homeostasis caused by environmental factors that exceed an individual's physiological and psychological resources to regulate (Tsigos & Chrousos, 2002). Due to the nature of their work, emergency PSP face physiological stress and psychological distress coming from alarm induced anxiety, cumulative CIE, and responsibility for safety of others (Guidotti, 1992). During acute stress, the ANS releases adrenaline which primes the fight or flight response by increasing heart rate and blood pressure to allow a more rapidly achieved steady state in response to the stress to return to homeostasis (Tsigos & Chrousos, 2002). Although homeostasis is the goal of the acute stress response, chronic states of stress can lead to dysfunction and manifest physically through anxiety and sleep disorders, depression, cognitive impairment, chronic fatigue syndrome, vascular remodelling, and symptoms of overtraining syndrome (Chu et al., 2020). Similar to athletes who experience overtraining symptoms of persistent fatigue and mood changes as a result of inadequate recovery, PSP are susceptible to this as a result of chronic psychological stress from CIE that presents as physiological, cognitive, emotional, and behavioral impairments (MacKinnon, 2000). With repeated exposure to psychological stressors through cumulative trauma from CIE, habituation to the stressor occurs with repeated and sustained hypothalamic-pituitary-adrenal axis activation (Tsigos & Chrousos, 2002). Habituation of the chronic stress response is an adaptive reduction in physiological reactions to repeated stressors (Grissom & Bhatnagar, 2008). Persistently elevated levels of chronic stress may lead to alterations in pituitary hormones, and these changes can lead to autonomic dysfunction as cortisol is depleted if chronic stress is unrelenting (Guidotti, 1992; MacKinnon, 2000; Selye, 1976). Hence, it is important to detect symptoms of chronic stress early. The stress reponse can be both subjectively assessed through self-reporting of symptoms, or more accurately determined through objective physiological testing. Self-report methods are not accurately capturing the occurrence of chronic stress in PSP, however, the physiological metric HRV may have the potential capability to improve early detection of autonomic dysfunction.

1.4 Autonomic Dysfunction and Heart Rate Variability

Autonomic dysfunction is the failure or overactivity of the sympathetic nervous system (SNS). As the SNS and parasympathetic nervous systems (PNS) are involved in systemic and organ regulation, dysfunction can be serious, impairing vascular control to the heart, kidneys, and brain (Mitani et al., 2006). Researchers have observed autonomic dysfunction among PSP, which has been attributed to the accumulation of the psychophysical demands of shift work pressures and CIE (Haugen, McCrillis, Smid, & Nijdam, 2017). Measuring HRV observes the temporal consistency of interbeat intervals of consecutive heartbeats, providing quantifiable insight of the cardiac response to stress that can be used as a marker of autonomic dysfunction in PSP (Kaikkonen et al., 2017). The heart is innervated by the SNS and PNS, with the SNS releasing catecholamines epinephrine and norepinephrine to accelerate HR and the PNS releasing acetylchonline to decelerate HR. Thus, HRV acts as a surrogate measure of autonomic function. A low HRV is suggestive of global autonomic hyperactivity, a feature of overtraining which is often accompanied by a higher HR that signifies chronic stress either physiologically, psychologically, or both (Kaikkonen et al., 2017). A decreased HRV at rest indirectly indicates that sympathetic nervous activity may be elevated, but the simplistic analysis may fail to provide specifics of the underlying cause of autonomic dysfunction, and whether or not it is related to an injury, illness, or psychological impairment (Tsigos & Chrousos, 2002). Due to potential technical and feasibility limitations, the reliability of HRV measures of autonomic function may be compromised in their range to ascertain the extent that HRV predicts stress. Analysis of HRV as a surrogate of autonomic function requires adherence to a strict measurement criteria (Catai et al., 2020).

1.5 Heart Rate Variability Measurement

The psychological trauma linked to CIE may impair autonomic function and assessments are required that will enable detectection of over-stressed states. Autonomic nervous system function can be directly measured via invasive protocols, or indirectly by HRV which measures the flexibility of the ANS to regulate HR in responding to and recovering from stress (Minassian et al., 2015). The optimal ways to measure autonomic function is directly via noradrenaline spill over where excess sodium excreted from organs indicate SNS hyperactivity, catecholamine and cortisol hormonal levels, or multi-unit postganglionic muscle sympathetic nerve activity measured with microneurography. However, these methods are nearly impossible to assess in the field, and require a high level of expertise (Fonkoue et al., 2020). Muscle sympathetic nerve activity measured using microneurography directly records SNS outflow to muscles and through peripheral nerves (Greaney & Kenney, 2017). Indirect HRV assessments are useable, but only if executed and interpreted correctly with standardization of collection parameters (Zygmunt & Stanczyk, 2009). To measure HRV accurately, environmental and individual factors must be considered. There are two main methods used to quantify HRV levels and fluctuations: 1) frequency domain; and 2) time domain (Hamilton & Alloy, 2016).

1.5.1 Frequency Domain Analysis of Heart Rate Variability

Frequency domain analysis aims to estimate the distribution of absolute or relative power of HRV into four bands: ultra-low-frequency (ULF), very-low frequency (VLF), low frequency

(LF), and high frequency (HF) (Shaffer & Ginsberg, 2017). The ULF band (<0.003 Hz) records for at least 24 hours and is correlated with the standard deviation of average NN intervals (SDANN) time-domain index as circadian rhythms and metabolism are the main contributors (Shaffer & Ginsberg, 2017). The VLF band (0.0033-0.04 Hz) records from 5 minutes up to and > 24 hours and is associated with PTSD as the heart intrinsically generates VLF rhythm and sympathetic nervous system (SNS) activity due to physical activity and stress responses (Shaffer & Ginsberg, 2017). The LF band (0.04-0.15 Hz) is recorded over a minimum of 2 minutes and is modulated by the SNS, PNS, and reflexive baroreceptor activity (Shaffer & Ginsberg, 2017). A HF (0.15-0.4 Hz) spectral band is a product of respiration and BP changes and a lower HF power is correlated with stress and anxiety (Wahbeh & Oken, 2013). Respiratory sinus arrhythmia (RSA) contributes to HF and is classified as vagal mediated fluctuations of HR during inspiration (increased) and expiration (decreased). Hayano and Yuda (2019) established that the framework to associate HRV frequency components with the divisions of the ANS is too simplistic, and is the major cause of misinterpretations regarding analysis and conclusions of findings. Frequency domain measures may fail to detect VLF oscillations, while time domain recordings are prone to external influences from confounding conditions (Xhyheri et al., 2012).

1.5.2 Time Domain Analysis of Heart Rate Variability

Time-domain analyses quantify the amount of HRV observed during time periods ranging from < 1 minute to > 24 hours (Shaffer & Ginsberg, 2017). Gold standard methods of calculating HRV use the temporal distance between sequences of intervals in the electrical R-spikes in heartbeat which can be quantified using electrocardiogram (ECG) (Xhyheri et al., 2012). There are many variations of parameters of time-domain analysis, but the two most used include: 1) standard deviation of NN intervals (SDNN), which encompasses 24 hour fluctuations in HR to describe HRV over time measured with an ECG; and 2) the square root of the mean squared differences of successive NN intervals (RMSSD) which describes short-term (5 minute) up to 24 hour variation and reflects parasympathetic activity (Shaffer & Ginsberg, 2017). The RMSSD measure can be taken using commercially available wearable devices such as wrist watches and/or chest strap technology. When considering utility and feasibility, time domain measures are the most practical approach to collecting data pertaining to mental health function and autonomic response. However a draw back is that time domain measures are less precise in indicating autonomic function outcomes and risk for worsening mental health. As multiple factors influence autonomic function, strict conditions must be adhered to when taking measurements (Zygmunt & Stanczzyk, 2009).

1.5.3 Behavioral Confounding Factors Affecting Heart Rate Variability

As HRV is a highly sensitive measure, various behavioral confounds can affect HRV in differing directions causing data skews. Prior to HRV collection, participants should receive guidelines advising them to avoid physical activity, consumption of alcohol, caffeine, nicotine, chocolate, soda, energy drinks, and medications for 24 hours prior to testing (Catai et al., 2020). These stimulating substances and activities alter HRV as they increase heart rate and subsequently decrease HRV. There is a dose related relationship between alcohol and HRV where two drinks daily increases HF power and decreases LF power (Spaak et al., 2010). Double that dose reduces time domain SDNN HRV by 10% and doubling again reduces it by 25% compared to no alcohol (Ryan & Howes, 2002). Caffeine found in coffee, energy drinks, and chocolate, releases cortisol which increases sympathetic nervous system activity, subsequently decreasing HRV (Sondermeijer et al., 2002). This directly impacts applicability of interpretation, for example, exercising and consuming coffee prior to on-duty PSP testing would not allow for discrimination between whether to attribute the decreased HRV and suggested mental health decline to those stimulating factors or to the CIE experienced on duty. Physical activity is recommended to be avoided for 24 hours prior to testing as it has been shown to cause decreases in HRV (Catai et al., 2020). Participants should be aware that failure to comply with the guidelines leading up to testing will result in disqualification from partaking on that day and would be cancelled or rescheduled (Board et al., 2016). In addition to the rigorous behavioural controls in place are necessary environmental factors to address.

1.5.4 Environmental Confounding Factors Affecting Heart Rate Variability

The autonomic system is sensitive to a host of different factors and if guidelines are not adhered to, the applicability of the findings are reduced. Hence, it is important for studies to be transparent in the reporting of factors that could impact the measurement of HRV by clearly stating the ways control was ensured. Studies must articulate randomization, blinding procedures or provide sufficient instructions for refraining from stimulants that will impact the autonomic system (Board et al., 2016). It is best practice that a familiarization session take place prior to the testing to acquaint the participant with the equipment and protocol to ensure the participant knows what to expect during actual testing (Catai et al., 2020). Best practice environmental control measures include having participants rested in a supine position for a minimum of 15-minutes in a quiet, dimly lit room free of distractions to ensure that extra stimulation from noises or bright lights do not stimulate the sympathetic nervous system which increase HR and lower HRV (Catai et al., 2020). Baseline and recovery measures are recommended to be taken for 15 minutes following the initial 15 minute rest period in a supine position to ensure the body is in a resting state and not being stimulated by movement (Catai et al., 2020). The data collection room is recommended to be at a controlled temperature (20 to 24 degrees Celsius) and relative humidity (40-60%) as overheating causes HR to rise and subsequently HRV to decline; in contrast, decreased body temperature is associated with reduced HR and increases in HRV (Stauss, 2003). Additionally humidity may affect respiration rate, impacting respiratory sinus arrhythmia (Stauss, 2003). It is advised that time of day for testing sessions are consistent among and across participants and taken in the morning due to circadian rhythms (Catai et al., 2020). Occurrences and clinical events are crucial to document as they will be imperative for later artifact removal and for providing explanation to drastic sudden changes in the data set. Failure to strictly implement these environmental conditions introduces the potential that the HRV values observed may not accurately represent the autonomic response in response to a CIE. Along with the many factors that affect HRV measurement comes challenges in lab to field application while maintaining the integrity of the rigor of the tests.

1.5.5 Challenges of Heart Rate Variability in Mental Health Assessment

HRV is a potentially important and complex measure in mental health assessment. Accurately determining if resting HRV provides the ability to determine mental health status requires rigorous procedures. The main challenge is establishing and maintaining realistic yet feasible protocols that represent activities carried out in practice while maintaining physiological validity. One option to overcome this challenge is to measure HRV while challenging autonomic reflex systems. A standardized array of tests that include a combination of several functional autonomic reflex stimulations can improve the validity of resting HRV measures alone. These tests provide an important opportunity to quantify the autonomic stress responses, and may help to characterize autonomic stress responses in mental health. Decreases in resting HRV are linked to ANS hyperactivity in individuals with mental health disorders. Similiarly, an exaggerated ANS response to a mild ANS stimulus may also indicate an underlying mental health issue (Hayano & Yuda, 2019; Ziemssen & Siepmann, 2019). Thus, to ensure ecological validity, best practices suggest that a functional HRV assessment involves 1) a physiological stress test response to assess the PNS; and 2) a functional test to assess the SNS such as blood pressure changes during a cognitive test, cold pressor test, or HRV recovery following exercise (Ziemssen & Siepmann, 2019).

Other challenges arise from interpretation issues with certain analytical outcomes. Studies that discuss frequency characteristics between sympathetic and vagal HR regulations are often over-interpreted (Hayano & Yuda, 2019). For example, a critical error is that LF and HF spectral components of HRV are used as separate metrics of sympathetic and parasympathetic functions which is an over-interpretation due to the influence of the baroreceptor reflex (Camm et al., 1996). Inferences about SNS activity cannot be made based on the beat to beat interval and many studies misinterpret LF power as a measure of SNS activity (Vanoli & Adamson, 1994). Only 6 of approximately 100 clinical studies reporting LF correctly interpreted that it is not a measure of SNS activity, but rather a measure of baroreceptor reflex cardiovascular regulation system which detects levels of stretch on vascular walls as blood volume increases (Heathers, 2014). Despite the evidence that the LF/HF ratio does not provide a measure of sympatho-vagal interactions (i.e., the balance between sympathetic and parasympathetic nervous activities), it continues to be published (Billman et al., 2013; Heathers, 2014). The mathematical ambiguity of the one dimensional ratio has since been resolved by incorporating two degrees of freedom for rigorous categorization of stress (Von Rosenberg et al., 2017).

Considering that these challenges are identifiable in nearly all HRV literature, a review of the literature to investigate current HRV measurement practices in mental health and PSP is needed. The proposed review of the literature will reveal which HRV measures are currently being used to aid early detection of PSP affected by mental health disorders, and the respective adherence to standardization of methodological approaches according to published guidelines to (Schneider & Schwerdtfeger, 2020). Ultimately, this review will help enhance the accuracy of interpretations in future studies to avoid the potential implication of diagnostic error (Billman et al., 2013).

1.6 Purpose

It is well known that autonomic dysfunction and mental health disorders are occurring in PSP but is not always measured appropriately via self-report and HRV (Carleton et al., 2018). Given the psychophysiological stress that PSP face and the negative impact that CIE has on health, it is important to develop an objective physiological measure in addition to subjective self report methods that will enable early detection of potential distress and mental health disorders to facilitate earlier access to treatment (Kehl et al., 2006; Morris & Rao, 2013). Currently, HRV is used to indicate chronic over-stress, but this highly sensitive measure can be performed inadequately if external factors are not controlled for, which can lead to misinterpretations regarding the prevalence, magnitude, and cause of autonomic dysfunction in PSP (Hayano & Yuda, 2019). To maximize the utility of HRV to determine autonomic dysfunction, it must be implemented with high levels of rigor. Hence, this study will characterize the occupational health literature via a scoping review to make recommendations to improve the way in which HRV is integrated into the applied mental health research. The purpose of this thesis is to characterize how HRV has been used to identify autonomic dysfunction and mental health disorders in PSP. The objectives are to 1) critically appraise the literature involving HRV assessment in identifying mental health disorders and/or autonomic dysfunction in PSP based on its scientific rigor, and 2) develop an infographic for researchers who use HRV as a measure of mental health that will highlight key factors to account for when measuring and interpreting HRV.

Chapter 2: SCOPING REVIEW

2.1 Introduction

Measuring AD using HRV has provided unique insights, however, whether or not HRV is being measured and interpreted while strictly following previously defined participant behaivoural and environmental measurement guidelines has yet to be investigated. Scoping reviews are designed to provide an overview of the available literature on an area of interest via a broad search and multiple structured strategies to capture all relevant information. Thus, this scoping review will identify how studies investigating mental health and/or AD in PSP have used HRV. The purpose is to gather all studies on this topic, and to reveal the scientific merit deemed by a quality appraisal, and finally develop a KT tool in the form of an infographic that can be used by researchers in the future.

2.2 Method

A scoping review of the literature was conducted using a five-stage framework developed by Arksey and O'Malley (2005) to summarize findings. To compile all applicable studies, five stages were followed: 1) identifying the research question; 2) identifying relevant studies via a search strategy; 3) study selection; 4) charting the data; and 5) summarizing and reporting the results (Arksey and O'Malley, 2005).

2.2.1 Identifying the Research Question

The review was guided by the research question; "How has HRV as a surrogate measure of autonomic dysfunction been implemented in research towards identifying mental health disorders among PSP?" The search strategy was carefully designed to encompass the objective of critically appraising the literature involving HRV assessment in identifying mental health disorders in PSP based on its scientific rigor.

2.2.2 Search Strategy

To comprehensively identify published studies relevant to the central research question, a search strategy was developed with the consultation of a library liaison. Steps for creating a search strategy outlined by Bramer and colleagues (2018) as well as the Peer Review of Electronic Search Strategies (PRESS) 2015 Guideline Evidence-Based Checklist by McGowan and colleagues (2016) were followed (Appendix B). Bibliographic databases Pubmed, Web of Science, Psycinfo, and CINAHL were searched using standard medical subject headings and keywords (Appendix C). Manuscripts were filtered to be written in the English language only. No limitations were placed for date of publications. Grey literature was searched for via the search strategy search terms in google scholar and open grey, however yielded no results that met the inclusion criteria.

2.2.3 Study Selection

Upon article retrieval using the search criteria identified, the study selection process followed the PRISMA flow diagram (Figure 1) beginning with duplicate article removal. The remaining articles underwent title and abstract screening for relevance based on inclusion and exclusion criteria. Eligibility criteria ensured that studies investigated the physiological response to CIE from a mechanistic perspective. Studies were eligible for inclusion if the following criteria were met:

a. Participant samples included PSP who experience CIE including but not limited to: military personnel, police officers, paramedics, and/or firefighters.
b. Studies included physiological quantification of autonomic function by measuring HRV.
c. Mental health disorders included either anxiety, PTSD, depression, chronic fatigue, substance use disorder, or cognitive impairment.
d. Studies were written in the English language.

Articles were excluded if they did not pertain to physiological identifiers of autonomic dysfunction in the mode of HRV, did not pertain to a PSP population, did not involve mental health, were a prospective protocol, or were not written in the English language.

2.2.4 Review Process

The initial search resulted in 518 records that were screened for inclusion in three phases. In the first phase, the author reviewed the 518 titles for duplicates. After duplicate removal, 474 records qualified for the title and abstract screening phase using the inclusion/exclusion criteria. Of the 79 abstracts that met eligibility criteria, 60 were removed upon full text review due to not having a measure of HRV (n=3), not having an inquiry to mental health (n=39), not involving a PSP population (n=7), being a review paper (n=8), not being written in the English language (n=1), and being a prospective protocol (n=2). Subsequently, a total of 19 articles were included in this review. The PRISMA flow chart details the study selection process (Figure 1).

2.2.5 Data Extraction

The following data were extracted for context documentation from all eligible studies (n=19): sample size, occupation, study design, how HRV was measured, mental health disorder, and summaries of the main findings (Table 1).

2.2.6 Quality Appraisal Methodology

The manuscripts underwent a critical appraisal assessment for quality via a 40-item "Study Design and Physiological Outcome Validity Appraisal Tool" found in Table 1 that was adapted from an Evaluation of Quality of an Intervention Study Tool (MacDermid et al., 2014) and a Physiological Outcome Validity Checklist (Catai et al., 2020). The Evaluation of Quality of an Intervention Study Tool involved criteria found in Table 1 questions 1-4, 6-12, and 37-40 taken from MacDermid (2014) which represented the critical appraisal score (C). The Physiological Outcome Validity Checklist (P) encompassed questions 5 and 13-36 extracted from Catai and colleagues (2020). The appraisal was performed using each tool independently and in combination using a hybrid appraisal to produce three summative scores reported for each study. The hybrid tool that encompassed all 40 questions combined, known as the total quality score (T), addressed study design, subject factors, experimental outcomes, and recommendations.

The tool guides a critical appraisal of published papers by assigning scores for each item where the description sounds most like what was reported in the study. Scores of 2 indicated strong research design, a 1 was suboptimal, a 0 was poor research design, and NA was not applicable. A higher score is indicative of a lower risk of bias, and greater study quality. A spreadsheet created on Microsoft Excel for Mac v. 16 documented the scoring of all papers from both reviewers, KS and AZ. To ensure validity of the tool and that consensus was achieved, both reviewers independently reviewed 2 papers and compared results. Reviewers KS and AZ discussed what constituted a score value for each category and individually assessed the remaining 17 studies. Disagreements among score assignment between raters (n=4) were resolved with discussion amongst the raters. If after that a consensus could not be met, the analysis of a third reviewer (KES) would have been utilized but this was not necessary as initial discussion achieved consensus. Discrepancies in scores were only present in 4 studies and upon discussion remained with the initial reviewer's (AZ) score. Scores were converted to percentages, and studies grouped into low (0-50%), medium (51-79%), and high (80-100%) quality categories as standard in previous studies (Stock et al., 2018). A low-quality rating reflects methodological limitations, including that relationships discovered between HRV and mental health may be attributable to factors which are not related to the CIE trauma in PSP.

Table 1.
Study design and physiological outcome quality appraisal tool criteria and evaluation guidelines for scoring.

STUDY DESIGN

1. Was there relevant and sufficient background work cited that led to a clear research question?
   -A literature review lead to a rationale for a question(s). A directional hypothesis and purpose used: patients, intervention, comparison, outcomes and timeframes – 2
   - All of the above were not fulfilled, nor was there a clear rationale – 1
   - The question was unclear with a lack of foundation - 0
2. Was a comparison group or control condition used?
   - Two or more same point in time groups of similar demographics were compared – 2
   - It was not clear that the groups were comparable – 1
   - No comparator group was included - 0
3. Was participant status at > 1 time point considered?
   - Participants were evaluated prior to the intervention, and at one or more relevant time point using the same evaluation process – 2
   - Participants were evaluated more than once (including case control studies), but the above criteria were not fulfilled – 1
   - Participants were evaluated at only one point in time - 0
4. Was data collection performed prospectively?
   - Data were collected at pre-set intervals according to a preplanned protocol (prospective cohort) – 2
   - Prospective data were collected across multiple intervals, and later retrieved from a database (retrospective) – 1
   - Data were from retrospective records or event recall - 0
5. Was the research setting suitable to infer possibilities of control (researcher interactions/distractions, noise)?
   - Yes, participants had their mobile devices removed during testing and did not interact with anyone, nor did anyone create noise or distractions – 2
   - The place was moderately suitable to infer control of interactions/distractions or noise. The participants mobile device was not removed during testing – 1
   - No, there were external interactions/distractions, excess noise, and the participants mobile device was not removed - 0
6. Were participants randomized to groups?
   - An appropriate randomization strategy was used – 2
   - Randomization was used, but it did not confirm a random process or the process was not described – 1
   - No - 0
7. Were participants blinded?
   - Yes, a description of blinding procedures or a post-hoc analysis indicated that blinding was effective; or it was evident that participants would be unable to distinguish which intervention they received – 2
   - Blinding was not possible or it was unclear whether an effective blinding strategy was used – 1
   - No (studies with no comparison groups) - 0
8. Were researchers blinded?
   - Researchers were blinded to the intervention – 2
   - Blinding was not possible or it was unclear whether an effective blinding strategy was used – 1
   - Blinding was possible, but was not utilized - 0
9. Were blinded analysis of outcome measure performed?
   - Yes – 2
   - Blinding was not possible or it was unclear whether an effective strategy was used – 1
   - Blinding was possible, but was not utilized - 0
10. Were independent evaluators used to analyze outcomes?
   - Yes – 2
   - No, but evaluators were not involved in treatment or self-report forms were administered by treatment providers – 1
   - No. Providers could have influenced the measurements - 0

EXPERIMENTAL OUTCOMES

19. Was temperature controlled for/recorded?
   - Yes, between 20-24 degrees Celsius- 2
   - Yes, but not between 20-24 degrees Celsius – 1
   - No - 0
20. Was humidity considered, controlled for, or recorded?
   - Yes, between 40-60%- 2
   - Yes, but not between 40-60% – 1
   - No - 0
21. Was time of day of measurements considered, controlled for, or recorded?
   - Time of day was consistently in the morning – 2
   - Time of day was consistent but not in the morning – 1
   - Time of day was not controlled for or consistent - 0
22. Was there a description of body position during data collection?
   - Yes, consistent among participants (supine or sitting) – 2
   - Yes, but not consistent among participants – 1
   - No description - 0
23. Was there a description of resting & dynamic conditions?
   - Yes – 2
   - Only of resting or dynamic conditions – 1
   - Neither condition was described - 0
24. Was baseline recorded with a rest of 15 minutes?
   - Yes – 2
   - Baseline was recorded but with a rest of < 15 minutes – 1
   - No baseline was recorded - 0
25. Were recovery, or follow up values recorded?
   - Yes for at least 15 minutes - 2
   - Yes but for <15 minutes – 1
   - No - 0
26. Was the signal acquisition rate described?
   - Yes and it was at least 1000 Hz - 2
   - Yes but was < 1000 Hz - 1
   - No - 0
27. Was the software used for acquisition described?
   - Yes and it was a valid software (e.g. Lab chart) - 2
   - Acquisition was described but software was not specified - 1
   - No – 0
28. Was the total length of signal acquisition time described?
   - Yes, as longitudinal (24 hour recording) - 2
   - Yes, but was not longitudinal (<24 hours) - 1
   - No - 0
29. Were occurrences (sneezes, coughs, or movements) and clinical events (dizziness, blurred vision, or arrhythmias) recorded before, during and after collection?
   - Yes - 2
   - Only during, but not during baseline or resting - 1
   - No -0
30. Was respiratory rate considered, controlled for and recorded?
   - Yes - 2
   - Importance was mentioned but it was not controlled for - 1
   - No mention of respiratory rate - 0
31. Were devices and their acquisition used to measure other physiological variables described?
   - Yes - 2
   - Devices but not their acquisition were described - 1
   - No or there were no secondary variables - 0

PARTICIPANTS

11. Did sampling procedures minimize sample/selection biases?
    - Sampling procedures were applied equally across groups – 2
    - Information on procedures or description of the population is not provided or there was no comparison group – 1
    - Sampling biases were evident; systematic differences occurred between comparison groups and/or selection procedures made it impossible to determine what types of people were included - 0
12. Were specific inclusion/exclusion criteria defined to identify a specific population?
    - Yes – 2
    - Insufficient information to identify a specific population – 1
    - No information on inclusion and exclusion criteria are stated; and limited participant descriptors are provided (e.g. 3 or less including age and gender) - 0
13. Was general health of the participants controlled/recorded?
    - Yes – 2
    - It was recorded but not controlled for – 1
    - No - 0
14. Were participants familiarized with the collection environment before recording data?
    - Yes on a different day - 2
    - Yes, but immediately prior to testing - 1
    - No - 0
15. Were nutrition/substance guidelines provided and adherence recorded?
    - Avoidance of alcohol, caffeine, medications for 24 hours prior to baseline testing was communicated and adherence was recorded and monitoring of substance's took place– 2
    - Guidelines were provided, but verification of adherence was not recorded or controlled for– 1
    - No guidelines were provided - 0
16. Were exercise and physical activity guidelines provided and adherence recorded?
    - Avoidance of physical activity for 24 hours prior to baseline testing was communicated, adherence was recorded and monitoring took place– 2
    - Guidelines were provided, but adherence was not recorded or controlled for– 1
    - No guidelines were provided - 0
17. Was an appropriate enrollment obtained?
    - A sample size calculation of a minimum of 80% power on the primary outcome measure was done and recruited the prespecified number of subjects – 2
    - A rationale for the number of subjects included in the study was not provided or the sample was >100 participants/per study arm – 1
    - Sample size was not justified - 0
18. Were participants interactions/distractions controlled for?
    - Yes – 2
    - Yes but they still impaired participant responses - 1
    - No or it was not stated that efforts were made to do so - 0

ANALYSIS

32. Was the software used to complete the analysis described?
    - Yes or it was referenced - 2
    - It was mentioned but not described - 1
    - It was not reported - 0
33. Was there a description of the selected sample of data processed?
    - Yes and it was representative of times of interest - 2
    - Yes but it was not representative of times of interest - 1
    - No - 0
34. Was the signal quality verified during processing?
    - Yes – 2
    - It was not reported, but could be inferred - 1
    - No - 0
35. Was editing and filtering the signal to remove artifacts during processing done?
    - Yes - 2
    - A need for it was described but it was not done - 1
    - No - 0
36. Was the # of beats and time window of analysis reported?
    - Yes - 2
    - Only the number of beats or the time window were reported - 1
    - Neither were reported - 0
37. Did the study have a priori driven subject numbers?
    - Yes - 2
    - It was not established, but could be inferred - 1
    - No - 0
38. Was missing data accounted for and considered?
    - Complete data collection was achieved or missing data was reported and where it occurred in more than 10% of cases, an imputation strategy was used - 2
    - Methods around missingness were not reported, but was not an issue (e.g. pretest post-test or cases from a database) - 1
    - The protocol for handling missing data was not described. It was not clear what % of data was imputed; or > 20% was imputed - 0

RECOMMENDATIONS

39. Were conclusions/interpretations supported by objectives/results?
    - Yes. Recommendations did not ignore results, over-generalize, or state that the treatment was ineffective when there was insufficient power to establish so – 2
    - Conclusions and clinical recommendations are incomplete, vague, or generalize to situations beyond those studied – 1
    - No conclusions/recommendations or it contradicted findings - 0
40. Were limitations of the findings discussed?
    - Limitations were transparently discussed addressing confounding factors – 2
    - Limitations did not address confounding factors – 1
    - No – 0

Total quality score = total sum/(80 - #NAs) x 100%
Physiological score = sum (Q5 + 13-36) – (#NAs) x 100%
Critical appraisal score = sum (Q1-4 + 6-12 +37-40) – (#NAs) x 100%

2.2.7 Data Synthesis and Analysis

To understand the effect of HRV on mental health in PSP, based on the main HRV and mental health conclusions, each study was given a yes, no, or yes and no to the whether HRV was correlated to mental health disorders or autonomic dysfunction in PSP. If a study found a significant association of lower HRV with outcome of autonomic dysfunction and/or presence of a mental health disorder, it was given a 'yes.' If a study found no significant association of HRV with outcomes of autonomic function and/or mental health, the study was given a 'no.' Finally, studies were characterized as 'yes and no' if there was partial support for low HRV correlating to autonomic dysfunction and/or presence of a mental health disorder, or it was supported in some but not all measures of HRV. The critical analysis of the physiological outcomes of the 3 highest quality studies were used to inform the HRV measurement guideline infographic for researches who use HRV to improve understanding of impacts of CIE trauma on mental health.

2.3 Results

Figure 1 presents detailed results of each phase of the literature search as well as reasons for exclusion of studies. The search identified 518 records. Following elimination of studies that did not meet the inclusion criteria, 19 studies were included for quality appraisal.

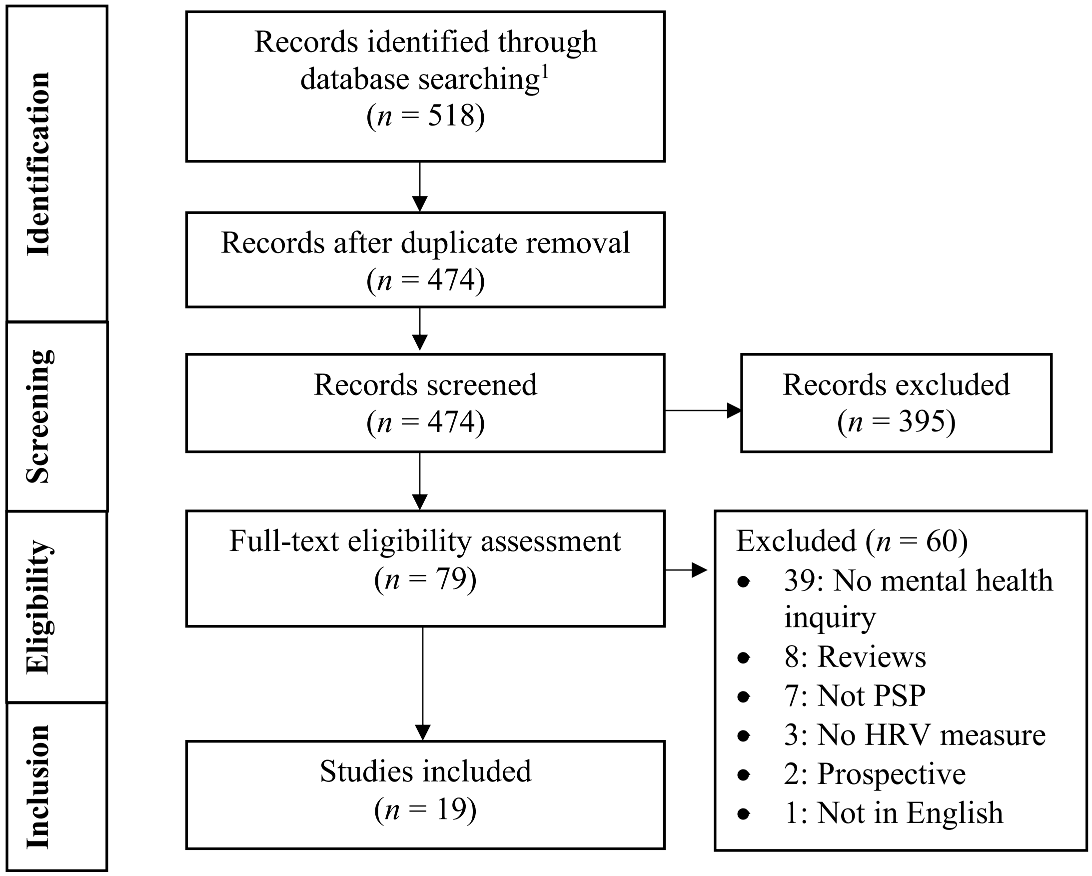

Figure 1. PRISMA flow diagram detailing the results of the search. [1]Number of records identified in individual databases (N=518): Pubmed: 249. Web of Science: 151. Psycinfo: 73. CINAHL: 45.

2.3.1 Demographics

Table 2 displays complete study demographics and main findings. From 19 studies, 4430 subjects over a span of the past 11 years across 4 professions were analyzed. Occupations consisted of paramedics, military personnel, police officers, and firefighters. Military personnel included soldiers, combat paratroopers, veterans, and marines. Participants were between the ages of 18-86. The sample included male and female participants with the majority of participants being male.

Table 2.

Description of the 19 studies included in the scoping review. Appraisal scores are represented as percentages where T represents total quality score, C represents critical appraisal score (MacDermid et al., 2014), and P represents physiological score (Catai et al., 2020).

First Author (year)	Participants	Mental Illness	HRV Measure	HRV Domain	Study Design	Main Finding	Score (%)	HRV correlated to mental health?
Tremblay (2020)	25 paramedics	PTSD	Secondary	Time (SDNN50)	Cross sectional	Elevated PTSD symptoms are linked with HRV.	T: 31 C:21 P:37	Yes
Hourani (2020)	261 military personnel & first responders	PTSD, anxiety, Depression, Alcohol misuse	Primary	Time (SDNN, RMSSD) & Frequency (LF)	Longitudinal	Lower LF HRV associated with worsened mental health.	T: 68 C: 78 P: 60	Yes
Krick (2020)	267 police officers	Anxiety	Secondary	Time (RMSSD)	2X2 Experimental mixed design	MBI resilience training improved HRV short and long term as indicated by increased HRV, more balanced sympathetic and parasympathetic activity, and improved ability to self-regulate.	T: 54 C: 75 P: 40	Yes
Speer (2020)	8 military personnel & first responders	PTSD, Depression, Anxiety	Primary	Time (RMSSD) & Frequency (LF, HF, ratio) & Nonlinear	Cross sectional	LnHF and LnRMSSD did not recover by 48 h post-exercise in the PTSD group.	T: 65 C: 69 P: 63	Yes
Kizakevich (2019)	49 military personnel & first responders	Anxiety, PTSD	Primary	Frequency (LF & RSA)	Longitudinal	With resilience training, changes were observed in arousal due to psychophysical states (rest, stress) via vagal-mediated RSA.	T: 55 C: 69 P: 46	Yes
Pyne (2019)	342 soldiers	PTSD	Primary	Time (SDNN) & Frequency (LF, HF)	Randomized control trial	The HRV biofeedback intervention demonstrated benefit at 3- and 12-months post-deployment.	T: 58 C: 81 P: 42	Yes
Oh (2018)	93 soldiers	Adjustment Disorder	Primary	Time (SDNN) & Frequency (VLF, LF, HF, LF/HF ratio)	Non randomized control trial	Baseline HF in soldiers with adjustment disorder was lower indicating lessened parasympathetic activity and baseline VLF was higher (sympathetic overactivity).	T: 66 C: 84 P: 54	Yes
Tornero (2018)	49 soldiers	Anxiety	Secondary	Time (RMSSD) & Frequency (LF, HF)	Cross sectional	The predisposition to a stressful stimulus, combat, increased sympathetic modulation in experimental groups as lower baseline RMSSD showed, meaning higher parasympathetic downregulation - a response consequent with an anticipatory anxiety response.	T: 35 C: 50 P: 25	Yes
Sanchez-Molina (2017)	19 urban combat paratroopers	Anxiety	Secondary	Time (RMSSD, SDNN) & Frequency (LF, HF)	Cross sectional	Urban combat increases sympathetic modulation and anxiety and decreases parasympathetic modulation.	T: 30 C: 50 P: 17	Yes
Tegeler (2017)	18 service members or veterans	PTSD, Anxiety, Depression	Secondary	Time (SDNN, RMSSD) & Frequency (LF, HF)	Longitudinal	HRV increased following the intervention in military personnel/veterans with PTSD.	T: 55 C: 59 P: 52	Yes
Pyne (2016)	343 soldiers	PTSD	Secondary	Time (SDNN) & Frequency (LF, HF)	Longitudinal	Pre-deployment HRV predicted post-deployment PTSD symptoms.	T: 50 C: 56 P: 46	Yes
Ramey (2016)	38 police officers	Anxiety, Depression	Secondary	Time (SDNN, RMSSD) & Frequency (VLF, LF, HF, ratio)	Longitudinal	Post stress-resilience intervention, mean parasympathetic component (HF) increased, while the sympathetic component (LF) decreased; RMSSD increased meaning increased parasympathetic activity countered by a decrease in sympathetic activity.	T: 54 C: 63 P: 48	Yes
Strahler (2015)	50 police officers	Anxiety	Secondary	Time (RMSSD)	Cross sectional	HRV decreased and anxiety increased from baseline during scenarios.	T: 53 C: 41 P: 54	Yes
Brisinda (2015)	113 police officers	Anxiety, Depression	Primary	Time, Frequency, Nonlinear	Prospective	HRV differentiated between mental and physical stress. LF/HF ratio was not reduced in stressful situations compared to daily activity. Predominance of LF was consistent with sympathetic activation.	T: 61 C: 53 P: 67	Yes & no
Liao (2014)	107 firefighters	Depression	Primary	Time (SDNN, SDNN index, RMSSD, pNN50)	Cross sectional	Depression was associated with lower RMSSD, SDNN index, and pNN50, but not with SDNN - inconsistent with previous studies.	T: 35 C: 38 P: 33	Yes & no
Minassian (2014)	2430 marines	PTSD, Depression	Primary	Time (SDNN, RMSSD) & Frequency (VLF, LF, HF, ratio)	Cross sectional	PTSD was associated with reduced HRV, but depression was not, contrasting what has been previously observed.	T: 49 C: 50 P: 48	Yes & no
Lee (2012)	125 military veterans	PTSD	Primary	Time (SDNN, RMSSD)	Retrospective	Veterans with PTSD had lower HRV than those without.	T: 43 C: 69 P: 25	Yes
Mccraty (2012)	65 police officers	ANS, Anxiety, Depression	Primary	Time (SDNN) & Frequency (VLF, LF, HF)	Longitudinal randomized control trial	Physiological and psychological stress in policing leads to high alcohol use, anxiety, and depression.	T: 54 C: 59 P: 50	Yes
Tan (2009)	28 military veterans	PTSD	Primary	Time (SDNN)	Cross sectional	There is a high prevalence of depressed HRV in veterans. Biofeedback HRV that could reduce ANS dysregulation by increasing HRV are supported.	T: 36 C: 30 P: 40	Yes

2.3.2 Quality Appraisal Results

The quality appraisal was separated into six main sections, as per the appraisal tool, to assess study design, subjects, experimental outcomes, secondary physiological outcomes, analysis, and recommendations. Each section within the complete results displayed in Table 3 will be further discussed. The critical appraisal tool involved 16 questions revised from MacDermid (2014) where 2 studies scored high quality (Oh et al., 2018; Pyne et al., 2019), 10 scored medium (Brisinda et al., 2015; Hourani et al., 2020; Kizakevich et al., 2019; Krick & Felfe, 2020; Lee & Theus, 2012; Mccraty & Atkinson, 2012; Pyne et al., 2016; Ramey et al., 2016; Speer et al., 2020; Tegeler et al., 2017), and 7 scored low (Liao et al., 2014; Minassian et al., 2015; Sánchez-Molina et al., 2017; Strahler & Ziegert, 2015; Tan et al., 2009; Tornero-Aguilera et al., 2018; Tremblay et al., 2020). The physiological appraisal consisted of 24 questions revised from Catai et al. (2020) and had 0 studies score high, 6 studies score medium, (Brisinda et al., 2015; Hourani et al., 2020; Oh et al., 2018; Speer et al., 2020; Strahler & Ziegert, 2015; Tegeler et al., 2017) and 13 studies score low quality (Kizakevich et al., 2019; Krick & Felfe, 2020; Lee & Theus, 2012; Liao et al., 2014; Mccraty & Atkinson, 2012; Minassian et al., 2014a; Pyne et al., 2016, 2019; Ramey et al., 2016; Sánchez-Molina et al., 2017; Tan et al., 2009; Tornero-Aguilera et al., 2018; Tremblay et al., 2020). The overall appraisal combining the critical appraisal and physiological appraisal consisted of 40 questions that had 0 studies were reported as high quality, 11 studies reported as medium (Brisinda et al., 2015; Hourani et al., 2020; Kizakevich et al., 2019; Krick & Felfe, 2020; Mccraty & Atkinson, 2012; Oh et al., 2018; Pyne et al., 2019; Ramey et al., 2016; Speer et al., 2020; Strahler & Ziegert, 2015; Tegeler et al., 2017), and 8 studies reported as low quality (Lee & Theus, 2012; Liao et al., 2014; Minassian et al., 2014a; Pyne et al., 2016; Sánchez-Molina et al., 2017; Tan et al., 2009; Tornero-Aguilera et al., 2018; Tremblay et al., 2020).

Table 3.
Quality appraisal scores (n=19) including overall quality score represented by P, the critical appraisal score represented by C, and physiological score represented by P. Ratings (R) are displayed as high (H), medium (M), or low (L).

Author (year)	Study Design										Subjects								Experimental Outcomes													Analysis							Recs		Scores T, C, P (%) & Rating (R)					
Criteria	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	31	32	33	34	35	36	37	38	39	40	T	R	C	R	P	R
Tremblay (2020)	2	0	0	0	1	NA	NA	NA	0	NA	1	1	2	1	0	0	1	1	1	0	0	2	NA	1	NA	2	1	2	0	0	0	1	1	0	0	0	0	0	1	1	31	L	21	L	37	L
Hourani (2020)	2	2	2	2	0	2	2	1	1	1	2	1	1	2	0	0	0	1	0	0	0	2	2	1	1	2	2	2	0	2	2	2	2	2	2	1	1	2	2	2	68	M	78	M	60	M
Krick (2020)	2	2	2	2	1	2	2	1	1	1	2	1	1	0	0	0	1	2	0	0	0	2	1	0	0	0	2	1	0	0	0	2	2	1	2	1	1	2	2	1	54	M	75	M	40	L
Speer (2020)	2	2	2	2	1	0	1	1	1	1	2	2	2	2	0	1	0	1	1	0	2	2	2	1	2	0	2	1	0	0	2	2	2	1	2	1	0	2	2	2	65	M	69	M	63	M
Kizakevich (2019)	1	2	2	2	0	2	2	1	1	1	2	1	0	2	1	0	1	2	0	0	0	0	0	1	1	0	2	2	0	1	0	2	2	2	2	1	1	1	2	1	55	M	69	M	46	L
Pyne (2019)	2	2	2	2	1	2	2	1	1	1	2	2	1	0	0	0	1	0	0	0	0	2	1	1	1	2	2	1	0	2	0	2	0	1	2	0	2	2	2	1	58	M	81	H	42	L
Oh (2018)	2	2	2	2	1	1	1	2	2	2	2	2	2	0	1	0	2	2	1	0	0	2	2	1	1	0	2	1	0	1	1	2	2	1	0	1	1	2	2	2	66	M	84	H	54	M
Tornero (2018)	2	2	2	2	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	2	1	0	2	1	0	0	2	2	0	1	0	0	0	1	1	1	35	L	50	L	25	L
Sanchez (2017)	1	2	1	2	0	2	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	1	0	0	2	2	0	0	0	0	0	1	1	1	30	L	50	L	17	L
Tegeler (2017)	2	0	2	2	1	0	1	1	1	2	1	2	2	1	1	0	0	0	0	0	2	2	0	1	1	2	2	1	0	0	2	2	2	1	2	0	0	2	2	1	55	M	59	M	52	M
Pyne (2016)	2	0	1	2	1	0	0	1	1	2	1	2	2	0	0	0	1	0	0	0	0	2	0	1	0	2	2	1	0	1	2	2	1	1	2	1	1	2	2	1	50	L	56	M	46	L
Ramey (2016)	1	1	2	2	1	2	1	1	2	1	2	0	2	0	0	0	0	0	0	0	0	2	1	0	0	2	2	2	0	1	2	2	2	1	2	1	0	2	2	1	54	M	63	M	48	L
Strahler (2015)	2	0	1	2	1	NA	NA	NA	1	1	1	0	1	0	1	1	0	2	0	0	2	2	1	0	2	0	2	1	0	0	2	2	2	1	2	1	0	0	2	2	53	M	41	L	54	M
Brisinda (2015)	1	0	2	2	1	0	1	1	2	1	1	1	2	0	1	1	1	2	0	0	2	2	1	2	2	0	2	1	1	1	2	2	2	1	2	1	0	1	2	2	61	M	53	M	67	M
Liao (2014)	1	2	0	0	1	0	0	1	1	1	1	0	1	0	0	0	1	0	0	0	0	0	1	0	0	2	2	2	0	0	0	2	2	1	0	1	0	2	2	1	35	L	38	L	33	L
Minassian (2014)	2	0	0	2	1	0	0	1	1	0	2	1	2	0	1	0	1	2	0	0	0	2	1	0	0	2	2	1	0	0	0	2	2	1	2	1	1	2	2	2	49	L	50	L	48	L
Lee (2012)	2	0	1	1	1	0	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	2	1	0	0	1	2	0	0	0	0	2	1	1	0	1	1	2	2	1	43	L	69	M	25	L
Mccraty (2012)	2	2	2	2	1	2	1	1	1	1	1	0	0	0	0	2	0	2	0	0	0	0	1	0	2	0	2	2	1	0	1	2	2	2	2	2	0	2	2	0	54	M	59	M	50	L
Tan (2009)	2	2	0	0	1	NA	NA	NA	0	0	0	1	0	0	0	0	0	NA	0	0	0	2	1	2	NA	0	2	2	0	0	NA	1	2	1	2	2	NA	NA	2	1	36	L	30	L	40	L

2.3.2.1 Study Design

The study design section comprised 10 questions of the critical appraisal which focused on the construct of design development. Based on the appraisal across 19 studies by two individuals, the construct of design develop was found to be of medium quality (61%). The previously defined criteria required that an unbiased literature review indicated what was known about the problem and established a clear gap and research question(s) with a rationale that supported a directional hypothesis and purpose statement. All studies met the standards in this area with the exception of 5 (Kizakevich et al., 2019; Liao et al., 2014; Minassian et al., 2014a; Ramey et al., 2016; Sánchez-Molina et al., 2017) that scored a 1 for not addressing all areas. The comparison of two or more contemporary (same point in time) groups of similar patients was incorporated in slightly over half of the studies. Participants were evaluated prior to the intervention, and at one or more clinically relevant time points, following the intervention using the same evaluation process in the majority, but not all studies with four only evaluating participants at one point in time (Liao et al., 2014; Minassian et al., 2014a; Tan et al., 2009; Tremblay et al., 2020). A standardized set of data were collected at specific pre-set intervals according to a preplanned prospective study protocol in all but 3 studies which used retrospective data sets not specifically design for their studies (Liao et al., 2014; Tan et al., 2009; Tremblay et al., 2020). The research location was moderately suitable to infer possibilities of control for interactions/distractions and noise in the majority of studies (Brisinda et al., 2015; Krick & Felfe, 2020; Lee & Theus, 2012; Liao et al., 2014; Mccraty & Atkinson, 2012; Minassian et al., 2014a; Oh et al., 2018; Pyne et al., 2016, 2019; Ramey et al., 2016; Speer et al., 2020; Strahler & Ziegert, 2015; Tan et al., 2009; Tegeler et al., 2017; Tremblay et al., 2020). No studies, however stated that participants mobile devices were removed from them during testing which can create distractions. An appropriate randomization strategy was used to allocate participants to interventions in 9 studies where it was suitable (Hourani et al., 2020; Kizakevich et al., 2019; Krick & Felfe, 2020; Mccraty & Atkinson, 2012; Oh et al., 2018; Pyne et al., 2019; Ramey et al., 2016; Sánchez-Molina et al., 2017). Participants were confirmed to have been blinded from the knowledge about which intervention they were partaking in just 5 studies (Hourani et al., 2020; Kizakevich et al., 2019; Krick & Felfe, 2020; Lee & Theus, 2012; Pyne et al., 2019). Fewer studies confirmed blinding of researchers to the intervention (Lee & Theus, 2012; Oh et al., 2018). Blinded analysis of outcome measures and administration of outcome measures was done by an evaluator who was blind to the treatment provided or the purpose of the study was clearly communicated in just 4 studies (Brisinda et al., 2015; Lee & Theus, 2012; Oh et al., 2018; Ramey et al., 2016). The last question evaluated if independent evaluators were used to analyze outcomes in which case 4 studies clearly stated so (Lee & Theus, 2012; Oh et al., 2018; Pyne et al., 2016; Tegeler et al., 2017).

2.3.2.2 Participants

The participants section consisted of 8 questions in the critical appraisal that focused on the constructs of sampling protocols and pre-testing guidelines. Across 19 studies, this section scored in the low quality range (37%). The previously defined criteria included that sampling procedures minimized sample/selection bias by being applied equally across groups. Authors had equal recruitment and sampling procedures across comparison groups in all studies but one that utilized convenience sampling which are often biased (Tan et al., 2009). This was one of the highest scoring criteria with the remaining studies scoring a 1 for failing to describe the population or procedures or not having no comparison group (Brisinda et al., 2015; Liao et al., 2014; Mccraty & Atkinson, 2012; Pyne et al., 2016; Sánchez-Molina et al., 2017; Strahler & Ziegert, 2015; Tegeler et al., 2017; Tornero-Aguilera et al., 2018; Tremblay et al., 2020) or a 2 for meeting criteria (Hourani et al., 2020; Kizakevich et al., 2019; Krick & Felfe, 2020; Lee & Theus, 2012; Minassian et al., 2014a; Oh et al., 2018; Pyne et al., 2019; Ramey et al., 2016; Speer et al., 2020). Defining specific inclusion and exclusion criteria for the study was not consistent among studies with less than half of the studies explaining this in detail enough to identify a specific population (Lee & Theus, 2012; Oh et al., 2018; Pyne et al., 2016, 2019; Speer et al., 2020; Tegeler et al., 2017). Many studies provided no information on inclusions and exclusion criteria and provided limited participant descriptors (Liao et al., 2014; Mccraty & Atkinson, 2012; Ramey et al., 2016; Sánchez-Molina et al., 2017; Strahler & Ziegert, 2015; Tornero-Aguilera et al., 2018). The general health of participants was controlled/recorded via a screening method in only nine of the 19 studies (Brisinda et al., 2015; Minassian et al., 2014a; Oh et al., 2018; Pyne et al., 2016, 2019; Ramey et al., 2016; Speer et al., 2020; Tegeler et al., 2017; Tremblay et al., 2020). Ensuring that participants were familiarized with the collection environment before recording data had extremely low adherence with only 4 studies mentioning this in more recently emerging studies (Hourani et al., 2020; Kizakevich et al., 2019; Speer et al., 2020; Tegeler et al., 2017). Nutrition and other substances control (alcohol, caffeine, medications for 24 hours prior, oral contraceptives) guidelines were provided for baseline testing in 6 studies (Brisinda et al., 2015; Kizakevich et al., 2019; Minassian et al., 2014a; Oh et al., 2018; Strahler & Ziegert, 2015; Tegeler et al., 2017) but adherence was not recorded or confirmed. Exercise and physical activity guidelines for baseline testing were provided in 4 studies (Brisinda et al., 2015; Mccraty & Atkinson, 2012; Speer et al., 2020; Strahler & Ziegert, 2015) and adherence was recorded and was monitored during testing in only 1 study (Mccraty & Atkinson, 2012). Appropriate enrollment was obtained in some studies which scored a 2 if authors performed a sample size calculation to provide a minimum of 80% power on their primary outcome measure and recruited the prespecified number of subjects which occurred in only 1 study (Oh et al., 2018). If a rationale for the number of subjects was not provided or the sample was >100 participants/study arm the paper received a score of 1 (Brisinda et al., 2015; Kizakevich et al., 2019; Krick & Felfe, 2020; Liao et al., 2014; Minassian et al., 2014a; Pyne et al., 2016, 2019; Tremblay et al., 2020). Researcher and participant interactions were controlled during data collection to not impair participant responses in 7 studies (Brisinda et al., 2015; Kizakevich et al., 2019; Krick & Felfe, 2020; Mccraty & Atkinson, 2012; Minassian et al., 2014a; Oh et al., 2018; Strahler & Ziegert, 2015). As these subject factors directly impact HRV experimental outcomes, more attention to detail is needed in this area for accurate interpretations of results.

2.3.2.3 Experimental Outcomes

Experimental outcomes comprised the largest section consisting of 13 sections focused on the constructs of controllable environmental factors and rigorous HRV testing data collection. In the quality appraisal, this section was given a low quality average score (38%). The previously defined criteria required that temperature was controlled for and recorded as between 20-24 degrees Celsius (Catai et al., 2020). Only 2 studies reported that temperature was controlled but not within the previously recommended range (Oh et al., 2018; Speer et al., 2020) consequently this is one of the lowest scoring areas along with controlling for a humidity of 40-60% which no studies mentioned. Time of day was considered, controlled for consistency among participants, and recorded in the morning in only 4 studies ((Brisinda et al., 2015; Speer et al., 2020; Strahler & Ziegert, 2015; Tegeler et al., 2017). There was a description of the participants body position during the collection and it was consistent in 70% of studies. A thorough description of the resting and dynamic conditions used during data collection was present in less than half of the studies. Baseline values of the volunteers were recorded with a rest of at least 15 minutes prior to collection in only 3 studies with an additional 9 studies recording baseline but for less than 15 minutes or without rest prior and 7 studies did not record baseline at all. Recovery, or follow up values were recorded for at least 15 minutes in 4 studies with an additional 6 studies recording for less than 15 minutes. The signal acquisition rate was described and was at least 1000Hz in 8 studies, one study was less than 1000Hz, and 9 did not mention signal acquisition rate. The software used for acquisition was described in detail and was a validated software in all but one study. The total length of signal acquisition time was described in detail and was longitudinal (24 hour recording) in 7 studies, with an additional 11 studies described as less than 24 hours and one less than 5 minutes. Occurrences (the subject sneezed, coughed, or moved body segments) and clinical events (dizziness, blurred vision, or arrhythmias) were recorded during collection in only 2 studies. Respiratory rate was considered, controlled for and recorded in 6 studies (Brisinda et al., 2015; Kizakevich et al., 2019; Oh et al., 2018; Pyne et al., 2016, 2019; Ramey et al., 2016). The devices and their acquisition used to measure other physiological variables simultaneous to autonomic measures as a secondary outcome were described in 11 studies (Brisinda et al., 2015; Mccraty & Atkinson, 2012; Oh et al., 2018; Pyne et al., 2016; Ramey et al., 2016; Sánchez-Molina et al., 2017; Speer et al., 2020; Strahler & Ziegert, 2015; Tegeler et al., 2017; Tornero-Aguilera et al., 2018). The attention to detail in experimental outcome scores directly impact the quality of analysis.

2.3.2.4 Analysis

The analysis section of the tool was comprised of 7 questions inquiring into the rigor of how HRV was analyzed. This section was given a medium quality score on average in the appraisal tool rating (59%). The previously defined criteria required that the software used in the analysis was reported and detailed or reference was made to more information and all studies adhered to this requirement. All studies met this criteria with the exception of the oldest and newest study published which mentioned but did not describe the software (Tan et al., 2009; Tremblay et al., 2020). The description of the selected sample of data processed was described and representative of times of interest in all but 3 studies (Pyne et al., 2019; Sánchez-Molina et al., 2017; Tornero-Aguilera et al., 2018). The signal quality was verified during processing or it could be inferred that it was in all but 2 studies (Sánchez-Molina et al., 2017; Tremblay et al., 2020). A need for editing and filtering the signal during processing for artifacts and outliers was described and implemented in 13 studies (Brisinda et al., 2015; Hourani et al., 2020; Kizakevich et al., 2019; Krick & Felfe, 2020; Mccraty & Atkinson, 2012; Minassian et al., 2014a; Pyne et al., 2016, 2019; Ramey et al., 2016; Speer et al., 2020; Strahler & Ziegert, 2015; Tan et al., 2009; Tegeler et al., 2017). The number of beats and time window in which analysis occurred was reported in 2 studies (Mccraty & Atkinson, 2012; Tan et al., 2009) with an additional 12 studies (Brisinda et al., 2015; Hourani et al., 2020; Kizakevich et al., 2019; Krick & Felfe, 2020; Lee & Theus, 2012; Liao et al., 2014; Minassian et al., 2014a; Oh et al., 2018; Pyne et al., 2016; Ramey et al., 2016; Speer et al., 2020; Strahler & Ziegert, 2015) reporting either number of beats or time window and 5 reporting neither (Pyne et al., 2019; Sánchez-Molina et al., 2017; Tegeler et al., 2017; Tornero-Aguilera et al., 2018; Tremblay et al., 2020). It was established or could be inferred that the studies had a priori driven subject numbers in less than half of studies (Hourani et al., 2020; Kizakevich et al., 2019; Krick & Felfe, 2020; Lee & Theus, 2012; Minassian et al., 2014a; Oh et al., 2018; Pyne et al., 2016, 2019). Complete data collection was achieved on all subjects or the rate of missing data was reported and where missing data occurred in more than 10% of cases, an appropriate imputation strategy was used in all but 2 studies (Mccraty & Atkinson, 2012; Tan et al., 2009).

2.3.2.5 Recommendations

The final section, recommendations, consisted of 2 assessment questions regarding the conclusions made and limitations of the findings. This section scored on the upper end of the medium range (78%) in the quality appraisal making it the highest quality section among studies.

Specific conclusions and clinical recommendations were made for each of the specific objectives of the study appropriately and recommendations did not ignore observed results or overstate the generalizability or clinical impact of the study findings in all but two studies (Tornero et al., 2018; Sanchez et al., 2017). The second criteria was that limitations of the findings were transparently discussed in detail addressing confounding factors which had a distribution of high, medium, and one low quality study score. A score of 2 was received in studies that transparently discussed and addressed confounding HRV factors (Brisinda et al., 2015; Hourani et al., 2020; Minassian et al., 2014a; Oh et al., 2018; Speer et al., 2020; Strahler & Ziegert, 2015). A score of 1 was received due to lack of discussing important confounding individual, environmental, or behavioural factors that impact HRV (Kizakevich et al., 2019; Krick et al., 2020; Lee et al., 2012; Liao et al., 2014; Pyne et al., 2019; Pyne et al., 2016; Ramey et al., 2016; Sanchez et al., 2017; Tan et al., 2009; Tornero et al., 2018; Tegeler et al., 2017; Tremblay et al., 2020). One study failed to discuss limitations at all which are very important in establishing the relationship between HRV and mental health/AD (Mccraty & Atkinson, 2012).

2.3.3 Relationship Between HRV and Mental Health

The main findings of the relationship between HRV and mental health (n=19) showed that in 84% of the studies there was a positive correlation. A total of 16 studies (Kizakevich et al., 2019; Krick & Felfe, 2020; Lee & Theus, 2012; Mccraty & Atkinson, 2012; Minassian et al., 2015; Oh et al., 2018; Pyne et al., 2016, 2019; Ramey et al., 2016; Sánchez-Molina et al., 2017; Strahler & Ziegert, 2015; Speer et al., 2020; Tan et al., 2009; Tegeler et al., 2017; Tornero-Aguilera et al., 2018; Tremblay et al., 2020) had a correlation where a lower HRV corresponded to worsened mental health/autonomic function. The remaining 3 studies (Brisinda et al., 2015;

Liao et al., 2014; Minassian et al., 2015) displayed mixed findings where the relationship was shown in some but not all aspects of the study, and no studies showed only no relationship.

2.4 Discussion

Following analysis of the 19 studies, a primary overarching theme and a subtheme emerged. The primary theme was that regardless of physiological adherence to a previously defined criteria or scientific merit, a decreased HRV is linked to worsened mental health as supported by the presence of a link in all studies despite the scoring on the quality appraisal. A subtheme was that many of the critical guidelines that outline confounding factors are not followed. Despite these confounding factors not being controlled or accounted for in the majority of studies, and regardless of the measurement technique, HRV was still linked to mental health in some form in all 19 studies. While a valuable observation, this finding is also problematic and concerning. The following discussion will detail the findings supporting the relationship between HRV and mental health in PSP, findings partially supporting the relationship, and the impact of not controlling for confounding factors in HRV measurement.

2.4.1 Findings in Support of the Link between HRV and Mental Health

Lower HRV was associated with worsened mental health and/or autonomic function in 16 studies. In the most recent study by Tremblay and colleagues (2020), elevated PTSD symptoms were linked with lower time domain SDNN50 HRV. Lower LF HRV, which is representative of sympathetic nervous system activity, was found to be associated with worsened mental health including PTSD, anxiety, depression, and alcohol misuse in military personnel and first responders (Hourani et al., 2020). In an experimental group with PTSD, HF and RMSSD HRV did not recover by 48 hours post-exercise, indicating worsened autonomic function than the control group (Speer et al., 2020). In soldiers with adjustment disorder, baseline HF was lower indicating lessened parasympathetic activity, and baseline VLF was higher suggesting sympathetic overactivity (Oh et al., 2018). Military veterans with PTSD presented with a high prevalence of depressed time domain SDNN HRV (Tan et al., 2009). The predisposition to a stressful stimulus, combat, increased sympathetic modulation in experimental groups as lower baseline RMSSD showed, meaning higher parasympathetic downregulation – a response consequent with an anticipatory anxiety response (Tornero et al., 2018). An urban combat maneuver produced a significant increase in sympathetic modulation and anxiety response as well as a significant decrease in parasympathetic modulation (Sánchez-Molina et al., 2017). At risk police officers were identified and recommended to partake in a 6 week self-regulation resilience training that improved 24 hour HRV recordings and reduced self-reported distress and depression (Mccraty et al., 2012). Interventions that could reduce ANS dysregulation by increasing HRV such as through HRV biofeedback are supported (Tan et al., 2009).

Studies have found that HRV biofeedback demonstrated benefit at 3 months and 1 year post-deployment in a large group (n=342) of soldiers (Pyne et al., 2019). Mindfulness based intervention resilience trainings improved HRV short and long term as indicated by increased HRV to represent more balanced autonomic activity and vagal mediated RSA in police officers, first responders, and military personnel (Kizakevich et al., 2019; Krick & Felfe, 2020). In a study with police officers, following a stress-resilience intervention HF HRV increased, LF decreased, and RMSSD increased meaning increased parasympathetic activity countered by a decrease in sympathetic activity (Ramey et al., 2016). There is a need for research with larger samples and rigorous psychophysiological HRV measurement to define relationships between PTSD and HRV as there are still mixed findings reported within the literature (Lee & Theus, 2012; Strahler & Ziegert, 2015). In a more recent study, a trauma exposed participant reported symptoms of PTSD but had no diagnosis, further stressing the importance of improving methods of early mental health detection in PSP (Speer et al., 2020). Future research would benefit from including objective measures such as HRV rather than only focusing on self-report (Kizakevich et al., 2019; Krick & Felfe, 2020; Mccraty & Atkinson, 2012).

2.4.2 Mixed Findings Supporting the Link between HRV and Mental Health

Three studies that all scored low to medium on all three appraisal scores, reported mixed findings of the ability for HRV to be indicative of mental health disorders and/or AD (Brisinda et al., 2015; Liao et al., 2014; Minassian et al., 2014). Brisinda and colleagues (2015) found that in policing scenarios, LF:HF ratio was not reduced in stressful situations compared to daily activity. A predominance of LF was consistent with prevalent sympathetic activation (Brisinda et al., 2015). When analyzed in the LF domain, HRV differentiated between mental and physical stress. This supports the potential for HRV to be used to improve understanding of autonomic responses with strict data collection and analysis methods (Brisinda et al., 2015). In another study with mixed findings, PTSD was associated with reduced HRV, but depression was not, contrasting what has been previously observed (Minassian et al., 2014). The third study reporting inconsistencies was in Liao and colleagues (2014) where depression was associated with lower RMSSD, SDNN index, and pNN50, but not with SDNN which includes all variation during 24 hours and may be influenced by physical activity which was not accounted for (Liao et al., 2014). These inconsistencies emphasize the importance of controlling for confounding factors in HRV measurement to ensure high accuracy in applied research.

2.4.3 Controlling for Confounding Factors in HRV Measurement

The analysis showed that because many studies apply HRV analysis as a secondary measure (Krick & Felfe, 2020; Pyne et al., 2016; Ramey et al., 2016; Sánchez-Molina et al., 2017; Strahler & Ziegert, 2015; Tegeler et al., 2017; Tornero-Aguilera et al., 2018; Tremblay et al., 2020), likely as a post-hoc analysis, adherence to strict methodological approaches are lacking. However, the relationship between HRV and mental health was still shown in all 19 studies with only three studies reporting mixed findings. Although the majority (n = 11) primarily intended on measuring HRV (Brisinda et al., 2015; Hourani et al., 2020; Kizakevich et al., 2019; Lee & Theus, 2012; Liao et al., 2014; Mccraty & Atkinson, 2012; Minassian et al., 2014a; Oh et al., 2018; Pyne et al., 2019; Speer et al., 2020; Tan et al., 2009), a large portion of studies involved it as a secondary metric (n = 8). Interestingly, the three studies which reported mixed findings (Brisinda et al., 2015; Liao et al., 2014; Minassian et al., 2014a) all had HRV as a primary measure within their experimental design, further highlighting the importance of re-examining the way that it is being implemented in studies. This highlights the relevance of ensuring that appropriate controls and experimental designs are implemented as the mix of responses provides insight into uncertainty of the measure. Pyne et al. (2016) stated that HRV is easy to measure, but confounds were not discussed in this study along with 7 others in this review (Tremblay et al., 2020). It is well-known that physical activity within 24 hours prior to testing affects HRV, yet a recent study performed a step test just prior to baseline testing which diminishes the credibility of the HRV measure (Tremblay et al., 2020). Acute bouts of physical activity can potentially skew the results positively as it decreases HRV, therefore, the cause for the presence of a link between lower HRV and mental health cannot be certainly attributed to the CIE experienced by the PSP.

Increasing the prevalence of apriori HRV testing in the form of a primary outcome measure rather than a secondary is fundamental for future research. This will allow for the data collection process to be more considerately thought out in applied settings and permit a more robust measure that limits type 2 error due to the many confounds. The physiological directionality of changes in areas including physical activity guidelines, nutrition and substance guidelines, temperature and humidity, time of day, respiratory rate, participant body position, and occurrences and clinical events during data collection are all critical to consider but are more often than not, overlooked. Furthermore, inclusion of a familiarization session, and strict baseline measures are important to be aware of and adhered to. Some studies did not report a baseline, therefore, there can be no causation of the alerted HRV and decline in mental health as it can be related to the CIE or another behavioural factor that is impossible to classify without the baseline measure. The goal is for future studies to conduct investigations with these metrics in place to have a more impactful and effective clinical outcome.

In order to clinically appraise an individual of being at risk for having mental health disorders because HRV is deviated from normal, a baseline must be taken. Within a population cross sectional comparison, this piece is missing and comparing a highly personal individualized measure to a relative population score is invalid. HRV is a robust measurement longitudinally, but a concern is that 7 studies in the review adopted a cross sectional research method (Liao et al., 2014; Minassian et al., 2014a; Sánchez-Molina et al., 2017; Speer et al., 2020; Strahler & Ziegert, 2015; Tan et al., 2009; Tremblay et al., 2020). Cross sectionally comparing groups is problematic since HRV cannot be characterized across different populations and compared against each other.

2.4.4 Limitations and Delimitations

The scoping review approach has several limitations. As scoping reviews describe available information, this requires a broad search and multiple structured strategies to capture all relevant information. Hence, the inclusion of multiple strategies and searching reference lists of articles, however, despite its necessity to ensure the validity of this process, some literature may be overlooked or go unread. Additionally, scoping reviews do not provide a synthesized result, but rather provide an overview of the available literature, which can be used to direct research questions. Subsequently, there was a risk for selection bias; however, this would be mitigated with the broad search criteria and quality appraisal form for bias assessment control. A final limitation was that within the physiological quality appraisal ranking, weighting of all of the factors was not implemented. It is likely that some factors carry greater impact than others in the changes to HRV, however, porportions are not currently known in the literature. Among the delimitations were the restriction to HRV as the method of autonomic dysfunction detection as the direct measures are beyond what the focus of this study is based on. The population of the study was delimited to PSP as they are the susceptible individuals of interest who experience high rates of CIE in the workplace.

2.4.5 Future Direction

Single screening methods of quantifying health may be problematic, causing either an underestimation of prevalence when using self-reported diagnosis or an overestimation when using individual screening tests (Tremblay et al., 2020). Considering that all studies reviewed showed some link between lowered HRV and worsened mental health, despite poor adherence to methodological guidelines, the primary outcome related to the scoping review is that HRV is a tool being used for detecting mental health disorders in PSP workers. Therefore, applied PSP research should take advantage of the objectivity provided in utilizing HRV to identify autonomic dysfunction in combination with self report assessments prone to response bias (Krick et al., 2020). Current diagnosis of PTSD in PSP workers does not involve physiological assessment. The overarching theme of this scoping review suggests that incorporating HRV as a metric to define physiological autonomic impairments that may be related to PTSD would provide evidence of potential autonomic dysfunction in the absence of a positive psychological assessment (Speer et al., 2020). By adding dynamic laboratory assessments of autonomic function (i.e., exercise, cold pressor testing, cognitive testing) in addition to HRV monitoring, researchers will be able to quantify how HRV and autonomic function interact in workplace settings with high CIE. Furthermore, there is a need for research with larger samples and rigorous psychophysiological HRV measurement to define relationships between PTSD and HRV (Lee & Theus, 2012), while also investigating interventional strategies to reduce autonomic dysfunction and mental health risk in individuals identified to be at risk. Nevertheless, by combining objective HRV measures with self report assessments, applied researchers and profesionals have an enhanced tool useful in the early detection autonomic dysfunction in PSP.

Considering that an underlying theme observed in this review was either the disregard or underreporting of adherence to HRV technical guidelines. A necessary point for future researchers to consider in order to properly roll out HRV as standardized tool, is the adherence to these technical guidelines described in detail above. This review provides a comprehensive discussion on the approaches required to accurately assess and analyse HRV in PSP. Despite this comprehensive discussion, it was determined that a more palatable summary of the most important factors to consider when measuring HRV in applied research. Thus, chapter 3 describes the details involved in translating the key components of the scoping review into an infographic. Ultimately this scoping review and the knowledge translation chapter below provide information that can be used to improve the accuracy and reproducibility of HRV as an indicator of autonomic dysfunction that can be used as an early indicator of mental health risk in applied PSP research.

Chapter 3: KNOWLEDGE TRANSLATION

3.1 Knowledge Translation

The Canadian Institutes of Health Research (CIHR) defines knowledge translation (KT) as a system of engaging researchers and knowledge users to provide effective solutions, products, and health care services (CIHR, 2016). The KT approach used for this project was an end of project KT which is where the implemented knowledge, in this case the infographic tool, is shared with the knowledge users, which are the researchers (CIHR, 2016). The goal of KT is to move research evidence into practice through knowledge inquiry, dissemination, and exchange (Collisson et al., 2011). Four overarching elements comprise KT including knowledge synthesis, knowledge dissemination, knowledge exchange, and ethical application (CIHR, 2016).

Knowledge synthesis, as the first element of KT was completed using a scoping review methodology. Knowledge synthesis examines research content and analytically evaluates the nature of findings to better understand the evidence for the topic, as done so by the scoping review (Arksey & O'Malley, 2005). Dissemination is the application of synthesis findings into tools for end-users, which will be an HRV measurement infographic tool for researchers to use in development of their research methods (McGowan, 2017). By means of the third element, exchange, evaluation and feedback from knowledge user stakeholders ensures appropriateness and applicability of the newly developed tool for best understanding of the context in which it will be applied (McGowan, 2017). Integrated KT (iKT) involving stakeholders ensures that outcomes are relevant to context and have a high level of utility. With a strong focus on the target audience of researchers, it was important to utilize an iKT approach where feedback from the knowledge users could be collected and implemented into the final project. Ethical application as a final component of KT is an important aspect of study dissemination, and as such must follow ethical principles and social values to protect the knowledge users (Graham et al., 2006). All responses collected will be anonymously conveyed in the thesis with numeric identifiers replacing names to ensure confidentiality of respondents.

3.1.1 Rationale for a KT Infographic

The first objective of this thesis was to critically appraise the literature involving HRV assessment in identifying mental health disorders in PSP based on its scientific rigor. The previous scoping review work identified that regardless of physiological adherence to scientific best practice standards for HRV measurement, HRV was linked to mental health in 84% of studies (Kizakevich et al., 2019; Krick & Felfe, 2020; Lee & Theus, 2012; Mccraty & Atkinson, 2012; Minassian et al., 2014; Oh et al., 2018; Pyne et al., 2016, 2019; Ramey et al., 2016; Sánchez-Molina et al., 2017; Strahler & Ziegert, 2015; Speer et al., 2020; Tan et al., 2009; Tegeler et al., 2017; Tornero-Aguilera et al., 2018; Tremblay et al., 2020). As HRV was linked to mental health in some capacity in all 19 of the studies, but the adherence to measurement guidelines were not of high quality, a KT piece is necessary to bridge the knowledge gap so that future investigations do not make erroneous claims that have significant health and safety implications. As HRV is a highly sensitive measure with many confounding environmental and behavioral factors that can alter results, type 1 or type 2 errors are likely to occur if best practices are not adhered to. Without using empirically sound measurement approaches, statistical errors may falsely detect autonomic dysfunction (type 1 error), or worse, leave a true case of autonomic dysfunction undetected (type 2 error). The KT gap is a lack of implementation of optimal HRV measurement protocols and appropriate interpretation for a given protocol in field research with PSP. Thus, the second objective was to develop a KT tool in the form of an infographic that provides simple guidelines explaining how to measure HRV for researchers who use HRV as a measure of autonomic dysfunction. The purpose of this infographic is to guide future research into maintaining highly rigorous standards of HRV measurement within the applied setting to assist with early intervention alongside psychological assessments in PSP suffering from autonomic dysfunction resulting from the high CIE experienced within their occupations.

3.2 Method

3.2.1 Infographic Development

An end of project KT model and conceptual framework for planning and improving evidence-based practices were used as the theoretical framework to engage stakeholders in the development of the HRV infographic tool (Graham et al., 2018; Spencer et al., 2013). The knowledge synthesis and knowledge tools/products of the knowledge to action framework were the goals of this KT project (Figure 2). The objective was to develop a KT tool for researchers based on the knowledge gap identified in the scoping review. The perceived knowledge gap is poor adherence to physiological guidelines in HRV measurement as a means of identifying worsening mental health. The mainly low to medium quality physiological appraisal scores, with only 2/19 of high physiological quality (Pyne et al., 2019; Oh et al., 2018), revealed in the scoping review demonstrates a lack of understanding or concern of the importance of following best practice experimental design. Therefore, the infographic tool is intended to be useful in bridging this knowledge gap by clearly outlining the critical components of HRV testing procedures and identifying what equipment is capable of performing respective types of measures. With this tool, knowledge users will have access to an interpretative guide on how to optimally measure HRV, how to analyze HRV metrics based on device used, and how to interpret results in regards to mental health.

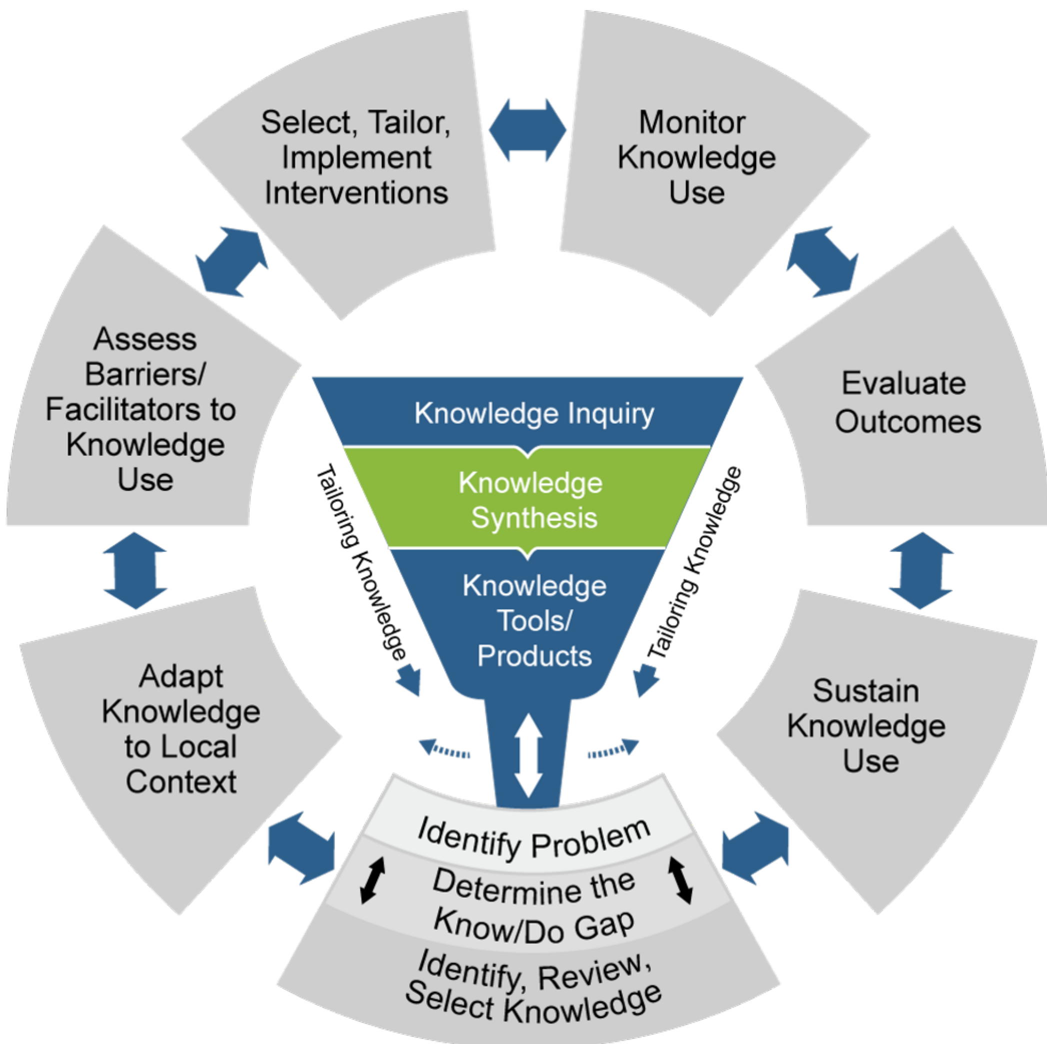

Figure 2. The Knowledge to Action Framework (Graham et al., 2006).

Figure 3. A conceptual framework for planning and improving evidence-based practices that informed the development of the KT infographic modified from Spencer et al., 2013.

The infographic provides measurement guidelines for researchers who use HRV as a measure of autonomic dysfunction to strengthen the quality of future studies (Spencer et al., 2013). The infographic titled "A Guide to Using Heart Rate Variability to Identify Mental Health Risk" shows that HRV is associated with worsened mental health in PSP in the majority of studies (n=15). It then included the following sections aimed at enhancing KT: Step 1) Baseline Testing Standardization; Step 2) Study Design; Step 3) Choose Device To Match Measurement and Analysis Need; and Step 4) Compare HRV During Intervention to Baseline. The synthesis of the scoping review included important concepts of experimental design considerations, HRV analytics and measurement devices, and interpretation in relation to mental health risk.

Following the conceptual framework by Spencer et al. (2013), the greater the quality of evidence, the greater the impact of the evidence is and vice versa (Figure 3). To maximize the impact, a KT tool was designed with hopes to increase the quality of evidence of future research to reach the high category for the best impact. As the physiological quality appraisal scores of 17/19 papers assessed in the scoping review were of medium to low quality, recommendations within the infographic were taken from the best practice guidelines that informed the physiological appraisal development (Catai et al. 2020). The recommended devices were informed by a recent review paper that assessed the suitability of wearable devices for monitoring HRV in a PSP population (Hinde et al., 2021). The interpretation of HRV results in application to detecting risk of mental health was derived from multiple papers that identified the relationship (Billman et al., 2013; Hayano & Yuda, 2019; Hinde et al., 2021).

3.2.2 Stakeholder Consultation

To evaluate the utility of the infographic tool to assess the applicability from an occupational health and safety researcher perspective, a sample of researchers (n=4) who use HRV as a measure of autonomic dysfunction to gain insights into mental health completed a questionnaire. The questionnaire involved three questions scored numerically on a scale of 1 to 5 with 1 being strongly disagree to a 5 being strongly agree regarding the clarity, utility, and feasibility (Appendix D). For the metric of clarity, the statement was: “the infographic was clear and easy to understand.” For the metric of utility, the statement was: “I see myself using the infographic in my research.” For the final metric of feasibility, the statement was: “this tool will assist in measuring HRV as a support measure of autonomic dysfunction to identify signs of mental health.” The next three questions of the questionnaire were written responses regarding what was the most liked aspect, what was the most difficult part to understand, and any additional feedback and/or suggestions. An email (Appendix E) was sent to researchers who use HRV in the applied setting with PSP or those who are working towards adding the measure in with psychological assessments. The email contained the infographic and the questionnaire for knowledge users to complete and return via email (Appendix D). Feedback and suggestions were then summarized and implemented to strengthen the clarity and utility of the tool.

3.3 Results

The first draft of a KT infographic for applied researchers who use HRV to measure autonomic dysfunction as a surrogate to mental health that was sent to researchers (n=4) for feedback/suggestions is presented in Figure 4. Table 4 displays scores from knowledge users (n=3) rating the infographic on a scale of 1-5 with 1 being strongly disagree and 5 being strongly agree for the factors of clarity, utility, and the ability to aid in measuring HRV as a measure of autonomic dysfunction to identify declining mental health. Table 5 contains summarized feedback from knowledge users (n=4) regarding the most liked aspect of the infographic, most difficult part to understand, and feedback and suggestions. The final product with knowledge user feedback incorporated is shown in Figure 5.

3.3.1 Initial KT Infographic

Shown in Figure 4 is the initial design for the KT infographic that was sent to knowledge users for their evaluation, feedback, and suggestions for improvement. The “Guide to Using Heart Rate Variability to Identify Mental Health Risk” consisted of a step-by-step, easy to follow format of how to measure HRV in PSP to identify risk of declining mental health. The infographic is introduced by a pie graph of the main findings of the scoping review, revealing that the majority of studies found that HRV was correlated to worsened mental health in PSP (n=16). The following sections headings were used to inform the readers: 1) baseline testing standardization, 2) study design, 3) devices and measurement and analysis needs, and 4) comparing HRV during intervention to baseline. This was emailed out to KT researchers within the network of the committee to utilize iKT by having them rate the utility, clarity, and applicability, as well as provide additional comments for stronger final outcomes.

Figure 4. The first draft of a KT infographic for applied researchers who use HRV to measure autonomic dysfunction as a surrogate to mental health that was sent to researchers for feedback/suggestions (n=3).

3.3.2 Knowledge User Feedback

Three participants responded to the complete questionnaire, and four provided written feedback. Table 4 summarized the responses of three raters who gave clarity (ease of understanding) a range of 3/5 to 4/5 resulting in an average of 3.6/5, and utility (I see myself using this) an average of 4/5. The final numeric rating question inquired about the ability to aid in measuring HRV as a measure of autonomic dysfunction to identify declining mental health which ranges in score from 3/5 to 4/5, resulting in an average rating of 3.3/5. The next section of the questionnaire collected written feedback regarding their most liked aspect of the infographic, the most difficult part to understand, and feedback and suggestions (Table 5). The raters (n=4) most liked that the infographic was presented with easy to follow steps, had clear icons, images, text, and information. The most difficult areas to understand consisted of identifying the difference between b and c in step 3 iii, the meaning of the pie chart and purpose of the flag image for rater 1, understanding the flow for rater 2, none for rater 3, and the analysis component and the differences between data capture constructs (PPG and ECG) for rater 4. The feedback and suggestions provided were integral in development of the final product and will further help to inform future research. Rater 1 suggested to expand on explanations for frequency domain variables, categorized devices by application, and improve theme consistency by expanding the tool into 2 infographics to 1) measure HRV; and 2) use HRV as a tool for assessing mental health. Rater 2 provided suggestions on organizational changes to improve flow, spelling out acronyms that users may not understand, and removing unnecessary categorizations of letter groupings to improve clarity. The third rater suggested to slightly reduce content if possible. The fourth rater liked having all of the information from data collection to analysis to interpretation on one page and suggested clarification regarding if frequency domain analysis was all obtained from the "b" and "c" category devices.

Table 4.

Scores from knowledge users (n=3) rating the infographic on a scale of 1-5 with 1 being strongly disagree and 5 being strongly agree for the factors of clarity, utility, and the ability to aid in measuring HRV as a measure of autonomic dysfunction to identify declining mental health.

Infographic Metric	Rater 1	Rater 3	Rater 4	Average
Clarity (Easy to understand)	4	4	3	3.6
Utility (I see myself using this)	4	4	4	4
Ability to aid in measuring HRV as a meaure of autonomic dysfunction to identify declining mental health	3	4	3	3.3

Table 5.

Summarized feedback from knowledge users (n=4) regarding their most liked aspect of the infographic, most difficult part to understand, and feedback and suggestions.

Infographic Metric	Rater 1	Rater 2	Rater 3	Rater 4
Most liked aspect	• Easy to follow steps (especially 1-3).	• Icons & images.	• Images, text, & info.	• Graphics & info.
Most difficult to understand	• The difference is between b & c in step 3 iii. • Pie chart meaning. • Purpose of the flag image.	• Understanding the flow.	• None.	• Differences between data capture constructs (PPG & ECG). • Analysis component.
Feedback & suggestions	• Better explain frequency domain. • Categorize devices by mechanical application for each intervention type. • Use graphics to explain 3 iii & 4. • To improve theme consistency, make 2 infographics with separate goals: 1) measuring HRV, and 2) HRV for assessing mental health.	• Move step 2 below step 1. • Lengthen to add more words. • Spell out acronyms. • Reword the top panel to: "in the majority of studies, Heart Rate Variability (HRV) is associated with worsened mental health in public safety personnel." • Only use i's & a's for the link between wearables and chart.	• Slightly reduce content.	• I like having all of the info (data collection, analysis, & interpretation) on one page • Clarify if frequency domain analysis is all obtained from b/c devices

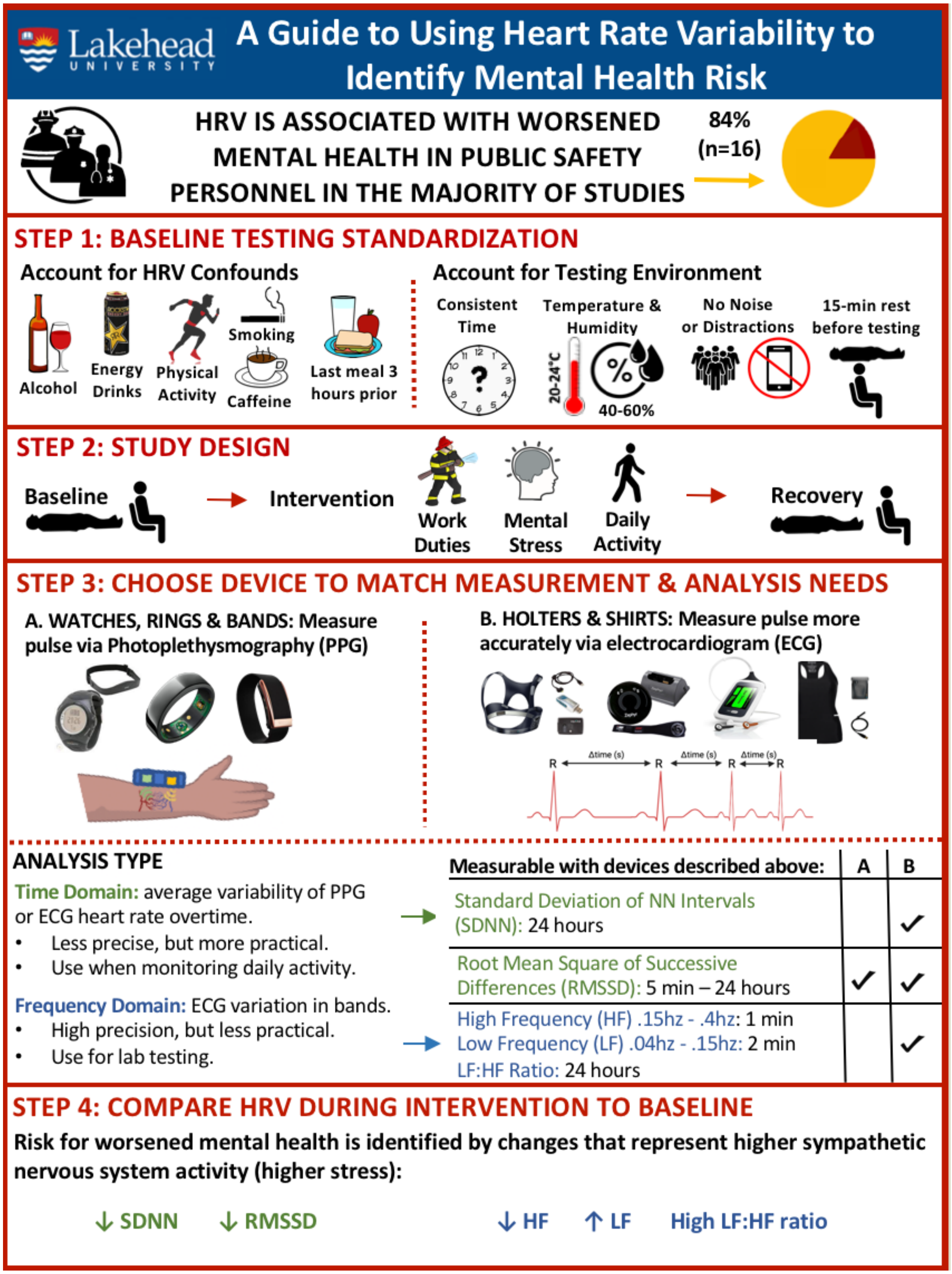

Figure 5. The KT infographic for applied researchers who use HRV to measure autonomic dysfunction as a surrogate to mental health that incorprorated feedback/suggestions from knowledge users (n=3).

3.4 Discussion

The purpose of the KT infographic is to provide an informative, easy to follow, and clear step by step measurement guideline tool for assessing HRV in PSP (Figure 5). The tool demonstrates that the relationship between HRV and mental health in PSP has been shown in 16 studies that have investigated the topic as found in the scoping review (Chapter 2). By illustrating important guidelines to implementing an optimal experimental design in steps 1 and 2, the infographic was determined to be useful for researchers investing mental health and autonomic function in PSP. Collectively, researchers were supportive of step 3, and its ability to expand on the types of devices and their corresponding measurement and analysis methods. However, more detail was requested with regards to how to interpret outcomes from the different devices (step 4) as the researchers felt there was a gap between steps 3 and 4. Considering step 4 is crucial to comparing HRV in PSP following characterization or intervention against baselines values, it was necessary to make sure that the transition between steps 3 and 4 was clear. The final revision of the KT infographic, through the integration of the stakeholders participation, provides important information to implement a sound scientific approach to determining the risk for worsened mental health.

3.4.1 Baseline Testing Standardization and Study Design

The beginning of the infographic outlines in step 1 factors to account for when standardizing baseline testing. The content regarding HRV experimental design was derived from the physiological appraisal questions from an HRV data collection checklist by Catai et al. (2020). One of the most important points to consider when designing a laboratory HRV assessment protocol is to include the necessary behavioural controls that could confound the

HRV signals for baseline testing. Confounding factors that impact HRV and should be accounted for include alcohol, energy drinks, physical activity, smoking, caffeine, and timing of the participants last meal. Accounting for these controls through documentation, a relative baseline will be available for each individual participant and thus deviations from baseline can be identified, and appropriate steps can be taken to determine if one of these factors is associated with a traumatic CIE.This more realistic approach of accounting for confounds rather than imposing restrictions that may further deviate the participant from their typical baseline measure, or ecologically valid behavior is a more feasible and reliable protocol for ensuring individual accuracy.

The environmental conditions that the testing is being conducted in are equally as important to account for, as multiple environmental factors influence HRV through relevant physiological responses. To eliminate artifacts in measurements and ensure validity among participants, it is important to test at a consistent time of day, maintain consistent room temperature and humidity, and limit noise or external distractions. The optimal experimental study design detailed in step 2 illustrates these points. For instance, all baseline and subsequent resting measures need to be consistently measured in either a seated or supine position. In instances a participant is engaged in an intervention such as PSP work duties, mental stress test, and/or daily activities, a follow-up recovery measure should be also taken in the same position as originally performed. This is important to ensure comparison measures and or recovery from stress is accounted for which provides the most robust assessment of physiologically relevant autonomic function. The third step guides the knowledge user on devices and corresponding analysis types depending on research goals. The user is asked to determine which device to use based on the specifics of the research questions and is described in more detail below.

3.4.2 Measurement Devices and Analysis

A crucial consideration to achieving a robust HRV assessment is which measurement device and analytical approach to utilize. Thus, in step 3, the measurement devices and HRV metric analysis portion of the infographic were provided to inform researchers on the difference between multiple HRV analysis processes that fit the appropriate devices. Depending on the desired monitoring outcome choosing the appropriate device and analyses greatly improve the scientific validity and reproducibility of HRV. This is important to avoid error resulting in a false positive, or worse, a missed negative which could leave PSP with mental health disorders undetected.

Watches, rings, and bands are categorized as group A, which measure pulse via photoplethysmography (PPG), common commercially available devices. Holters and shirts are categorized as B measurement devices which measure the timing of beat to beat pulse separation more accurately via electrocardiogram (ECG). Below these devices is the breakdown of analysis types. Time domain analysis utilizes the average variability of PPG or ECG heart rate over the duration of the measurement, but is only considered relevant to AD by measuring the changes between multiple 24 hour periods (Shaffer & Ginsberg, 2017). This measure is less precise than frequency domain, as it does not take into account the beat to beat temporal comfort and simplistic instrumentations these measurement devices provide. They are more comfortable to wear for extended periods, and are more cost effective in comparison to frequency domain devices. Time domain can be used when monitoring daily activity. Although there are many types of time domain measurement, the two most common ones were incorporated in the chart colour coded in green to indicate that they belong to the time domain grouping. Standard deviation of NN intervals (SDNN) requires 24 hours measurement and can be measured only used B devices (holters and shirts). The SDNN measurement requires 24 hours of continuous data measurement to be valid, but is the most accurate measure of time domain due to the greater accuracy of ECG heart rate interval measures compared to PPG. Root mean square of successive differences (RMSSD) can be measured by either A (watches, rings, and bands) or B (shirts and holter) devices. The RMSSD measure can be taken from a range of 5 minutes to 24 hours with the longer measures being the most representative. The advantage of this method is that it can be useful when less than a 24 hour time frame is available for testing. It can therefore be used to potentially reveal HRV shifts that occur prior to, during, or following a specific incident while performing a PSP or daily activity. Shown in blue are frequency domain measures which can only be measured with B devices containing ECG. The ECG signal measured continuously provides researchers the ability to calculate the standard deviation between R-R intervals with high temporal resolution of at least 1000 Hz, whereas time domain merely takes into account the average change in heart rate. Thus, frequency domain provides a more robust analysis with regard to determining mechanistic deviations in autonomic dysfunction (i.e., estimated increases in SNA). Frequency domain measures vary in the length of required measurement. For LF, which represents mostly sympathetic nervous system activity, only 2 minutes are needed to generate values. For HF, which represents mostly parasympathetic nervous system activity, only 1 minute of recording time is necessary. However, to be able to draw conclusions from the LF:HF ratio, 24 hours of recording are done for best practice. Frequency domain measures although more difficult to implement, yield greater precision when interpreting changes in HRV in relation to autonomic dysfunction, and subsequently evaluating mental health risk.

3.4.3 Compare HRV During Intervention to Baseline

The final section briefly summarized how to interpret changes in HRV in relation to mental health risk. The risk for worsened mental health is identified by changes that represent higher SNA, which is impacted by higher stress levels (Jung, Jang, & Lee, 2019). Within time domain, worsened mental health risk is detected via a significantly lowered SDNN or RMSSD HRV (Jung, Jang, & Lee, 2019). Within frequency domain, worsened mental health risk is detected via significantly lowered HF, increased LF, or a high LF: HF ratio (Shaffer & Ginsberg, 2017). This concluding piece is the most important for the goal of detecting mental health risk, but is only feasible if all of the other parts before it are adhered to. Hence, this is where misinterpretation may result in type 1 or type 2 errors.

3.4.4 Stakeholder Consultation

Table 5 summarized the feedback regarding their most liked aspect of the infographic, the most difficult part to understand, as well as feedback and suggestions. The feedback from knowledge users was informative and guided the development of the final product. All suggested changes were made with the exception of reformatting the infographic into 2 pages to highlight the ultimate purpose of using HRV as a tool for assessing autonomic dysfunction. Instead, step 4 was expanded to explicitly describe how the HRV metrics coincide with sympathetic vs. parasympathetic nervous system branches to indicate stress levels. As rater's had conflicting stances on increasing content and reducing content, the infographic was reduced in some areas such as unnecessary graphics and categorizations, and better explained in others, for example, the link between HRV and mental health. The pie graph heading was altered to better explain the meaning and the as the purpose of the flag image was not clear, it was removed. To help with the understanding of the flow, step 2 was moved from beside step 1 to below it for a clear vertical organization of steps 1 to 4. The “i” and “a” categorizations were removed from each section and only included to aid in linking the wearables with the chart of HRV analysis types to reduce complexity. For the time domain analysis types, acronyms were spelled out. Finally, as the difference in step 3 iii between b and c was difficult to understand, they were merged together into one grouping. Future research may wish to expand on this concept and use an integrated KT approach working with stakeholders throughout the research process to further improve researcher’s understanding of the concepts.

3.4.5 Limitations and Delimitations

The KT infographic has two distinct limitations. First, the realm of HRV measurement guidelines is extremely vast, and therefore the information provided within the KT infographic does not cover every possible consideration. However, the most overlooked, and confounding factors that must be considered have been expressed. Additionally, when these factors are considered, other extraneous issues are remedied. There is a fine line between providing overly abundant versus insufficient information that is made increasingly difficult when limited by the space of one page that is also aesthetically pleasing to not overwhelm the reader and discourage use. The hazard of delivering succinct information is that it may oversimplify the outcomes. This issue is delimited by providing the options for data capture, and outlining which device may be best for each situation. Secondly, stakeholders were not directly involved in the KT approach to provide input into the development of the infographic that is intended for their use. Our approach to incorporate their reviews in refining the infographic however should delimit this by integrating their insight and expertise in the final draft.

3.4.6 Future Direction

This thesis work has identified key characteristics for integration of KT in applied HRV research. Following the findings of the scoping review, the HRV guideline infographic was built upon the KT elements and findings of objective 1. Future researchers will be able to use the infographic to guide their methods involving HRV measurement in applied settings. Additionally, to continue making advancements, future research in the field of KT could work directly with researchers using iKT approaches to further assess the impact of the tool and make advancements such as expansions recommended by stakeholders. This will help to enhance accuracy of interpretations in future studies to avoid the potential implication of diagnostic error (Billman et al., 2013).

3.5 Conclusion

This thesis aimed to review the literature on the use of HRV as a metric to identify mental health disorder risk in PSP, as well as construct a HRV measurement guideline KT tool for improving quality of future study protocols. The overarching theme that emerged from the scoping review was that regardless of physiological adherence to scientific merit, a decreased HRV was linked to worsened mental health in all 19 studies. Three of these studies did report mixed findings, but these mixed findings were likely related to the analytic technique. A subtheme that was revealed by the scoping review was that despite many critical confounding factors not being controlled for, HRV was still linked to mental health in all studies. Considering the link between HRV and mental health, in addition to the poor scientific rigor, an important piece for this thesis was to add an element of KT. The themes and subtheme were used to develop a KT infographic tool for researchers who use HRV as a measure of mental health risk in PSP.

Single screening methods of quantifying health may be problematic, potentially resulting in either an underestimation of prevalence when using self-reported diagnosis or an overestimation when using individual screening tests (Tremblay et al., 2020). Therefore, using HRV as an objective physiological measure will help to aid with early identification of mental health disorders in PSP. As the primary findings of the scoping review indicated that all studies showed some link between lowered HRV and worsened mental health despite being rated as having low to medium quality appraisal scores, future studies would benefit from implementing the KT tool to guide methods involving HRV measurement to enhance the accuracy of interpretations in future studies to lower the risk of diagnostic error (Billman et al., 2013). It is imperative to avoid measurement and analytical error to reduce the probability of type 1 error, a falsely detected decline in mental health, or a type 2 error, a missed detection in declining mental health in a PSP. Long term outcomes of using the KT tool will improve the quality of studies with aims to improve from the current low to high quality average scores to best quality scores, subsequently improving the impact based on the conceptual framework for planning and improving evidence-based practices. Overall, the implementation of the KT tool will help with earlier detection of worsening mental health identified by changes in HRV.

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Appendix A: Checklist of procedures for capturing and processing HRV

The checklist of procedure to follow for capturing and processing heart rate variability was used to inform development of the hybrid critical appraisal tool (Catai et al., 2020).

Table 1 Checklist of procedures to follow for capturing and processing heart rate variability.

Item	Questions
1	Was the general health of the volunteers 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 familiarised 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 min prior to collection?
13	Was there a description of the volunteer's body position during the collection?
14	Was there a description of the volunteer's dynamic/rest during the collection?
15	Was there any control of the volunteer's interactions during the collection?
16	Was there any control of the volunteer's distractions during the collection?
17	Were ocurrences (the subject sneezed, coughed, dozed or moved body segments) recorded before, during and after the collection?
18	Were clinical events (dizziness, blurred vision, arrythmias, 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 the 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 volunteer's 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 time window in which the analysis occurred reported?
30	Were the stationarity criteria of R-R interval times series described?

Appendix B: Search Strategy Development Checklist and Methodology

PRESS 2015 Guideline Evidence-Based Checklist

Translation of the research question	• Does the search strategy match the research question/PICO? • Are the search concepts clear? • Are there too many or too few PICO elements included? • Are the search concepts too narrow or too broad? • Does the search retrieve too many or too few records? (Please show number of hits per line.) • Are unconventional or complex strategies explained?
Boolean and proximity operators (these vary based on search service)	• Are Boolean or proximity operators used correctly? • Is the use of nesting with brackets appropriate and effective for the search? • If NOT is used, is this likely to result in any unintended exclusions? • Could precision be improved by using proximity operators (eg, adjacent, near, within) or phrase searching instead of AND? • Is the width of proximity operators suitable (eg, might adj5 pick up more variants than adj2)?
Subject headings (database specific)	• Are the subject headings relevant? • Are any relevant subject headings missing; for example, previous index terms? • Are any subject headings too broad or too narrow? • Are subject headings exploded where necessary and vice versa? • Are major headings (''starring'' or restrict to focus) used? If so, is there adequate justification? • Are subheadings missing? • Are subheadings attached to subject headings? (Floating subheadings may be preferred.) • Are floating subheadings relevant and used appropriately? • Are both subject headings and terms in free text (see the following) used for each concept?
Text word searching (free text)	• Does the search include all spelling variants in free text (eg, UK vs. US spelling)? • Does the search include all synonyms or antonyms (eg, opposites)? • Does the search capture relevant truncation (ie, is truncation at the correct place)? • Is the truncation too broad or too narrow? • Are acronyms or abbreviations used appropriately? Do they capture irrelevant material? Are the full terms also included? • Are the keywords specific enough or too broad? Are too many or too few keywords used? Are stop words used? • Have the appropriate fields been searched; for example, is the choice of the text word fields (.tw.) or all fields (.af.) appropriate? Are there any other fields to be included or excluded (database specific)? • Should any long strings be broken into several shorter search statements?
Spelling, syntax, and line numbers	• Are there any spelling errors? • Are there any errors in system syntax; for example, the use of a truncation symbol from a different search interface? • Are there incorrect line combinations or orphan lines (ie, lines that are not referred to in the final summation that could indicate an error in an AND or OR statement)?
Limits and filters	• Are all limits and filters used appropriately and are they relevant given the research question? • Are all limits and filters used appropriately and are they relevant for the database? • Are any potentially helpful limits or filters missing? Are the limits or filters too broad or too narrow? Can any limits or filters be added or taken away? • Are sources cited for the filters used?

Abbreviation: PICO, population/problem, intervention/exposure, comparison, outcome.

Peer Review of Electronic Search Strategies (PRESS) for evidence syntheses (McGowan et al., 2016).

Creating a Systematic Search Strategy

The methodology outlined by Bramer and colleagues (2018) for planning and creating a multi-database search strategy was followed:

1. Determine a clear and focused question
2. Describe the articles that can answer the question
3. Decide which key concepts address the different elements of the question
4. Decide which elements should be used for the best results
5. Choose an appropriate database and interface to start with
6. Document the search process in a text document
7. Identify appropriate index terms in the thesaurus of the first database
8. Identify synonyms in the thesaurus
9. Add variations in search terms
10. Use database-appropriate syntax, with parentheses, Boolean operators, and field codes
11. Optimize the search
12. Evaluate the initial results
13. Check for errors
14. Translate to other databases
15. Test and reiterate

Appendix C: Search Strategy Methodology: Objective One

Database	Subject Headings & Keywords
Pubmed (n=249)	(“Mental Health” [Mesh] OR “Stress Disorders, Post-Traumatic" [Mesh] OR “Fatigue Syndrome, Chronic” [Mesh] OR “Alcohol-Related Disorders” [Mesh] OR “Substance-Related Disorders” [Mesh] OR “Cognition” [Mesh] OR “Mental Health" [All Fields] OR "PTSD" [All Fields] OR "Post-traumatic stress disorder" [All Fields] OR "Anxiety" [All Fields] OR "Depression" [All Fields] OR "Chronic fatigue syndrome" [All Fields] OR "Alcohol use disorder" [All Fields] OR "Substance use disorder" [All Fields] OR "Cognition" [All Fields] OR "Chronic Stress" [All Fields] OR "Critical incident" [All Fields] OR "autonomic function" [All Fields] OR "autonomic dysfunction" [All Fields] OR "Autonomic nervous system" [All fields] OR “Autonomic Nervous System” [Mesh]) AND (“Heart Rate/physiology” [Mesh] OR "HRV"[All Fields] OR "Heart Rate Variability" [All Fields]) AND ("Military Personnel" [Mesh] OR "Emergency Responders" [Mesh] OR “Physicians” [Mesh] OR "Police" [All Fields] OR "firefighters" [All Fields] OR "Paramedics" [All Fields] OR "Physicians" [All Fields])
Psycinfo (n=73)	("Heart Rate Variability" OR "HRV") AND ("Autonomic function" OR “Autonomic dysfunction” OR "autonomic nervous system" OR "Post Traumatic Stress" OR "Mental Health" OR "anxiety" OR "depression” OR "chronic stress" OR "Psychological Stress" OR “Critical incident” OR “cognition” OR “Substance use disorder” OR “chronic fatigue” OR “Alcohol use disorder”) AND ("Emergency Personnel" OR "First Responders" OR "Paramedic*" OR “Physician*” OR ("police officer" OR "police officers") OR "Military Personnel" OR "Firefighter*")
Web of Science (n=151)	(TS=(“first responder*” OR “public safety personnel” OR firefighter* OR paramedic* OR “police*” OR “military personnel” OR physician*)) AND (TS=(“critical incident” OR “mental health” OR “anxiety” OR “depression” OR “chronic fatigue” OR “substance use” OR “alcohol use” OR “PTSD” OR “post traumatic stress disorder” OR “cognition” OR “chronic stress” OR “autonomic nervous system” OR “autonomic function*” OR “autonomic dysfunction”)) AND (TS=(“heart rate variability*” OR “HRV”))
CINAHL (n=45)	((“Military Personnel” OR “First Responder” OR “Public safety personnel” OR “Police” OR “Firefighter*” OR “Physician*” OR “Paramedic*”) AND ((“Heart Rate Variability” OR “HRV”) AND ("Autonomic Nervous System" OR “autonomic function” OR “Autonomic dysfunction” OR (“Post-Traumatic stress disorder”) OR “PTSD” OR (MM "Fatigue Syndrome, Chronic") OR “Mental health” OR “Critical incident” OR "Substance Use Disorders" OR “Alcohol use disorder”)

Appendix D: User Interface Feedback Questionnaire

User Feedback Questionnaire for "HRV Measurement Infographic Tool"

The HRV measurement tool is an infographic designed to assist researchers who use this measure to identify autonomic dysfunction and/or mental health disorders in public safety personnel.

Please select the option that best describes your opinion on the feasibility and utility of this infographic as it could be applied to your research.

1. The infographic was clear and easy to understand.

   Strongly Disagree 1 2 3 4 5 Strongly Agree

2. I see myself using the infographic in my research.

   Strongly Disagree 1 2 3 4 5 Strongly Agree

3. This tool will assist in measuring HRV as a support measure of autonomic dysfunction to identify signs of declining mental health.

   Strongly Disagree 1 2 3 4 5 Strongly Agree

4. Do you have any feedback/suggestions?

   ____

Appendix E: Email Correspondence to Potential Participants

Subject: Invition to Complete a Questionnaire about an HRV Measurement Infographic Tool

Email Content:

"Hello,

My name is Andrea Zapcic and I am an MSc candidate at Lakehead University under the supervision of Dr. Kathryn Sinden and Dr. Kurt Smith. As a knowledge translation component of my thesis, I developed an HRV infographic to assist researchers who use HRV in the applied setting, specifically to measure mental health and/or autonomic dysfunction in public safety personnel. I am hoping that you can complete a brief survey and provide your opinion on the feasibility and utility as it applies to your work. Your responses will be anonymous and will be helpful in developing future tools to support researchers. If you would like to voluntarily participate in this questionnaire, please kindly fill out a short survey attached to this email and return it to Andrea Zapcic: akzapcic@lakeheadu.ca.

Thank you very much for your time and consideration. If you have any questions or concerns, please do not hesitate to contact me.

Sincerely,
Andrea Zapcic"