Heart Rate Assessment for Posttraumatic Stress Disorder Symptoms among Military Veterans: A Narrative Literature Review

Posttraumatic Stress Disorder (PTSD) is a prevalent psychiatric condition among Americans. The total costs for providing medical care for returning veterans of Iraq and Afghanistan range from $40-54 billion. A preventive approach that focuses on early intervention and treatment for PTSD and comorbid illnesses such as depression and improved integration into society after deployment that allows for decompression might be one of the ways to improve outcomes and reduce long-term medical care costs. The paper documents our findings from a narrative review conducted to investigate psychophysiological and technological interventions especially heart rate for designing a systems solution for narrowing the gaps in PTSD care along with the current research gaps in that field of literature.

INTRODUCTION

Post-Traumatic Stress Disorder (PTSD) is a prevalent psychiatric condition in United States. A recent study puts the PTSD prevalence in the civilian population around 11% of the total population and 24.5% of the veterans population (Spottswood et al., 2017). As much as 20% of the returning veterans from the current wars in Afghanistan and Iraq are diagnosed with PTSD (Ramchand et al., 2010). Assessment and intervention methods for PTSD symptoms among veterans is an important need that should be addressed to faster recovery and reintegration into society. Another important aspect is bridging the gap between therapeutic sessions at one end of the spectrum and self-care at the other end. An early recovery process from PTSD symptoms that happens when patients are outside of the clinic might help in part to reduce isolation and dissociation for military veterans.

This review aimed to examine the literature on techniques and methods for detection and measurement of PTSD symptoms. Additionally, this review also focused on identifying technologies that can bridge the gap between helping patients when they are in-between therapeutic sessions with a clinician to inform the design of a PTSD continuous monitoring tool. The literature review identifies gaps in the research, draws out a plan to address these shortcomings and provides key insights from interviews conducted with veterans to improve the current PTSD care system.

METHODS

A narrative review was conducted using the strategies outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2009). This review intended to examine the literature on posttraumatic stress disorder (PTSD), to investigate the current techniques for detection and measurement of PTSD and the intervention techniques available to mitigate its symptoms.

The initial search were conducting using the terms “PTSD," "PTSD presentation," “PTSD physiology," “PTSD diagnosis," “PTSD symptoms," “PTSD reactions," and “PTSD signatures.” This search yielded a large number of results. In the second search, to narrow the scope to mitigation and intervention techniques a different search was carried out including terms such as “Stress Disorders”, “Post-Traumatic”, “PTSD OR post-traumatic stress disorder or posttraumatic stress disorder or post-traumatic stress disorder”, “PTSD OR “post-traumatic stress disorder OR posttraumatic stress disorder OR post-traumatic stress disorder” and were combined using Boolean modifier “AND” with search terms such as “veterans” OR “veteran or military OR soldier.” Search terms such as “photoplethysmography device” OR “photoplethysmogram” OR “ppg/hr” OR “photoplethysmogram”, "heart rate," "stress disorders," "post-traumatic" OR "post-traumatic stress disorders," "resting heart rate," and "baseline heart rate” were used to further narrow down to heart rate s monitoring for PTSD care specifically.

A search through the databases of Medline, PsycINFO, social science abstracts and Compendex, using the predefined inclusion and exclusion criteria, yielded a total of 121 papers that were included in this review. Relevant reviews and seminal papers associated with PTSD treatment, psychophysiological measurements, the prevalence of PTSD in military veterans, detection of PTSD and severity of PTSD were included. Laboratory-based brainmapping techniques, and neurological assessment studies were not the focus of this review and therefore were excluded.

RESULTS

Military veterans diagnosed with PTSD might also suffer from anxiety, depression or both. Rates of triple (PTSD, anxiety, depression) comorbidity are in the range of 26.7-30.1%, which is higher than the rates for PTSD alone (9.3-11.1%), comorbid with depression (1.2-4.5%) or anxiety (2.9-4.5%) (Ginzburg et al., 2010). Studies show veterans with PTSD have reduced hippocampal volume (Childress et al., 2011, in Whitworth & Ciccolo, 2016), and HPA dysfunction. A reduced hippocampus volume can lead to short-term memory loss and disorientation (Sherin & Nemeroff, 2011, in Whitworth & Ciccolo, 2016). Veterans diagnosed with PTSD tend to also have more violent sleep behaviors and hallucinations (Ohayon & Shapiro, 2000, in Genc et al., 2011). In addition, psychotherapeutic and pharmacotherapies are more effective for non-veteran population and not as effective on veterans (Watts et al., 2013, in Whitworth & Ciccolo, 2016). These characteristics in addition to the social stigma associated with PTSD showcase the difficult situation veterans' face while recovering from PTSD (Gibbons et al., 2014).

The following section pertains to the symptom of hyper-arousal from PTSD and its association with physiological measures.

Methods for objective assessment of PTSD symptoms

Psychophysiology is used to assess and gain an insight into PTSD. Psychophysiology involves the non-invasive recording of biological processes simultaneously (Pole, 2007). The commonly used physiological measures to assess PTSD that can also be used outside of the lab and discretely are: (1) heart rate (cardiac activity); (2) heart rate variability (HRV) (3) galvanic skin conductance (GSC); (4) systolic blood pressure (SBP); and (5) diastolic blood pressure (DBP) (Pole, 2007). Other measures include startle-eye blink and habituation/extinction paradigms that have shown promise in distinguishing between PTSD and non-PTSD samples (Jovanovic et al., 2012; Morgan et al., 1996; Straus et al., 2017, in Colvonen et al., 2017). It has been shown that under conditions of distress these measures show an increase and can be used to assess the severity of an anxiety attack such as a PTSD episode. The physiological measures may help distinguish between patients that respond well to treatment and non-responders to treatment (Colvonen et al., 2017). All these measures have a unique signature individually and can be used to provide additional information regarding PTSD's pathophysiology (Pole, 2007). It should be noted that these physiological measurements have often been taken under controlled conditions in a laboratory and research is needed to field test these measures for a more naturalistic view of PTSD.

Most studies have used four overarching protocols in conjunction with these psychophysiological parameters in a laboratory environment to assess PTSD symptoms: (1) resting baseline; (2) exposure to startling sounds; (3) exposure to standardized trauma cues; and (4) exposure to idiographic trauma cues (Pole, 2007). Pole's (2007) meta-analysis of studies to assess psychophysiological measures to detect PTSD found that some measures are significant for one of the four above-mentioned protocols and not for the others, in regards to testing for a PTSD and non-PTSD sample. The measures that the meta-analysis found to be reliably related to PTSD are: (1) higher resting heart rate; (2) larger heart rate responses to standardized trauma cues; and (3) for idiographic cues facial muscle electromyography (EMG) and heart rate responses. Heart rate, an important parameter to detect PTSD symptoms, is assessed in the next section in detail.

PTSD and heart rate

Heart rate is one of the psychophysiological measures that show reliable results regarding association with hyper-arousal symptoms of PTSD (Pole, 2007). Pole's (2007) paper lists higher resting heart rate as one of the factors associated with PTSD from heart rate measurement. Some of the theories put forth to describe changes in heart rate are: 1) higher resting heart rates are due to a permanent shift in the baseline as a result of increased cardiovascular responses to stress in PTSD (Fredrikson & Matthews, 1990; Georgiades & Fredriksson, 2000, in Buckley & Kaloupek, 2001); 2) emotional apprehension or priming; priming is anticipatory anxiety where patients' exhibit increased arousal in anticipation of exposure (Prins et al., 1995; in Buckley & Kaloupek, 2001) 3) theories related to confounding variables that affect heart rate and are associated with PTSD.

It was found that there was a five beats per minute (bpm) increase in resting heart rates for combat veterans with and without PTSD (Beckham et al., 2000, Woodward et al., 2009). Buckley et al. (2004) found that for a mixed population (veterans and civilians) resting heart rate increase of 6.6 bpm for PTSD positive as compared to non-PTSD patients while adjusting for covariates. Further, two major studies the Framingham study (Kannel et al., 1987) and The National Health and Nutrition Examination Survey (NHANES) I Epidemiologic Follow-up Study (Gillum et al., 1991) have stated that elevation in the parameter resting heart rate for individuals is an independent risk for cardiovascular mortality. Higher rates of alcohol abuse in military veterans were associated with PTSD (Kulka et al., 1990, in Buckley & Kaloupek, 2001). PTSD is also associated with excessive smoking (Beckham et al., 1998, in Buckley & Kaloupek, 2001). Lustyk et al. (2012) have stated that early onset of heart disease may be an outcome of military service among PTSD positive veterans.

The following section explores the relation between heart rate analyses for detection of stress.

Stress detection using heart rate

Studies have shown the connection between chronic stress and cardiovascular diseases (McEwen, 1998; Segerstrom and Miller, 2004). The exact mechanisms of how stress affects health are not well known, however, it is possible to observe stressful events and relate these to physiological changes in heart rate that can be measured using modern sensors. A real-time personal stress monitor may benefit users by providing continuous feedback about their stress levels over a period (Andreoli et al., 2010).

HRV monitoring to measure stress, anxiety, and depression has become a widely-accepted method for it is a non-invasive measurement during sleep as well as activity periods (Holt et al., 2016). HRV has been used in the literature to differentiate between stressed and non-stressed conditions. The time series for the R-R intervals are divided into segments that are known as response curves. Features commonly used in psychological concepts such as peak amplitude, standard deviation, area to full recovery, etc. are extracted from the time series. These features are then fed to a classification algorithm based on experimental evidence of inducing stress in participants and normal conditions. A strong and regular HRV is associated with good neurophysiological function whereas a weak and irregular variability is linked to poor neurophysiological function and stress (Cohn et al., 2013). Heart rate variability biofeedback (HRVB) is an example of non-invasive treatment for patients that have a dysregulated vagal nerve (issues with parasympathetic component of ANS). This approach is promising in treatment for various stress-related disorders such as PTSD and depression and might show clinical improvement by integrating HRVB training in combination with psychotherapy (Blasé et al., 2016).

Heart rate analysis techniques and limitations

In the literature, heart rate is analyzed using statistical, geometric, frequency domain analysis, time-frequency and non-linear feature analysis. The most widely used time domain or statistical features are average heart rate, standard deviation of the heart rate and the root mean square of the standard deviation of heart rate. These statistical features need filtering of the data to remove outliers (Acharya et al., 2006).

Poincare plots is a nonlinear geometric feature as a geometric measure of heart rate signal (Woo et al., 1992). The Poincare plot is used in heart rate variability (HRV) analysis in which an RR interval is plotted as a function of the previous RR interval. The plot provides an overview as well as beat-to-beat information about heart rate. The Poincare plots are useful in the detection of chronic conditions such as atrial fibrillation (AF), ventricular fibrillation (VF), Ischemic cardiomyopathy, periventricular contraction (PVC), complete heart block (CHB), etc.

Frequency domain analysis is used to assess autonomic nervous system (ANS) components sympathetic and parasympathetic components. The low-frequency component of the frequency analysis is not understood, as it is modulated by both components of the ANS and the baroreceptors (senses pressure changes in the arteries). Despite advanced preprocessing, the very low frequency (VLF) and ultra-low frequency (ULF) components of frequency analysis have reduced reliability with a decrease in signal power and signal-to-noise ratio. In addition, frequency analysis provides information regarding activation of ANS components on a global scale. If location-specific information in the signal is lost, it might not provide adequate information about subtle changes in heart rate (Akaike, 1969, 1974).

Non-linear features have been developed to quantify the dynamics of HR fluctuations. Approximate entropy is one of the important non-linear measures that checks the order or regularity of a signal. Normal heart rates would have higher order, and abnormal heart rate will have lower order values. A feature of approximate entropy is that it can detect subtle abnormal changes in heart rate. However it might not be able to detect changes in prolonged abnormality of signal (Pincus, 1991).

Detrended fluctuation analysis (DFA) is another non-linear feature used to characterize fluctuations in the signal (Huikuri et al., 2000). This method can differentiate between normal subjects and subjects with AF, VF, PVC, etc. Lyapunov exponent is a non-linear feature that indicates the intensity of the chaos in the system. This feature is utilized to differentiate amongst conditions that have low variation in the signal (e.g., CHB) to progressively higher variation in the signal (Acharya et al., 2004). The Hurst component measures the smoothness of a factual time series based on the asymptotic behavior on a logarithm scale. Fractal dimension is another non-linear feature that measures of the degree of complexity that compares the actual number of units that create a curve to the number of minimum number of units required to reproduce the same curve on a larger or smaller curve. A normal healthy adult will have a more complex rhythm compared to an abnormal curve of a person with reduced variation in the HRV. Recurrence plots (RPs) are used to reveal non-stationarity of the time series. The plot examines hidden periodicities in the data. RPs have been used to detect ventricular tachycardias as they reveal slow variations in ventricular tachycardias as compared to normal variations in HR. Correlation dimension (CD) provides the nature of the trajectory of a phase space plot. Normal subjects have higher values of CD because of the higher variation in HR as compared to abnormal or lower variations in HR (Acharya et al., 2006).

DISCUSSION

Several research gaps were identified as a result of this narrative review. It seems that veterans prefer discrete methods that don't draw attention for the treatment of PTSD, discrete non-invasive sensors provide a plausible solution. Heart rate detection for non-continuous assessment is usually carried out by electro-cardiograph (ECG) sensors in studies. Most of these sensors are not discrete, and there is a need to study wearable sensors that can continuously monitor heart rates discretely without anyone noticing that the person is wearing a sensor. Additionally, the negative stigma attached to PTSD should be considered; a patient may not wear a sensor that draws attention to their condition. A non-invasive sensor such as the photoplethysmography (PPG) can collect heart rate measurements discretely and non-invasively. Studies have not focused on using PPG sensors in wearables to examine heart rate related symptoms of PTSD using continuous monitoring.

In addition, Pole's (2007) meta-analysis findings in support of Griffin et al. (1997) and Pole et al. (2006) suggest that regulation of physiological response in PTSD might be more important than magnitude of response. For instance, emotional numbness might show muted responses in PTSD patients showing dissociation, and in that case magnitude might not be significant. Magnitude is usually associated with heart rate measurement in research studies instead of individual baselines.

Studies have not focused on continuous monitoring of PTSD patients in their natural surroundings, where they are comfortable for most of their time, and a trigger in the form of loud noises or a crowd might push them into a hyper aroused state. Startle responses in a laboratory vs. in a natural environment might show differences in symptom characteristics for PTSD. Naturalistic studies might bring in a different perspective on how heart rates for PTSD patients differ prior to and after triggering of PTSD symptoms. Continuous heart rate studies might also provide insight into the understanding of any significant correlation between other factors mentioned detailed in Xue et al. (2015), and Hynes &

Thomas (2016) studies for military veterans diagnosed with PTSD.

Heart rate analysis reviewed in the literature suggests a link between PTSD symptoms and differences in PTSD and non-PTSD subjects (Pole, 2007), but a characterization of PTSD symptoms from heart rate data seems to be a research gap. Continuous monitoring of physiological parameters has not been studied to infer key characteristics associated with PTSD among military veterans that highlight muted response to startle or treatment. Characteristics of the symptoms can be analyzed from heart rate baselines while they occur in a natural environment and compare that to a controlled study to identify differences. There is also a research gap in the assessment of heart rate accelerations and decelerations when monitoring PTSD symptoms for patients (Khanade et al., 2017). These research gaps point out a need to examine continuous monitoring of heart rate in PTSD patients to improve assessment and supplement treatments with acute interventions.

The HRV analysis provides a more chronic picture of PTSD symptoms. In order to draw an inference from HRV, a large sample is required to derive time-domain and frequency domain measures. A more acute characterization of PTSD symptoms can be implemented using continuous monitoring of instantaneous HR to improve prediction and detection of PTSD symptoms, in attempt to create awareness towards hyper-arousal symptoms. These research gaps could be addressed to improve PTSD care outside of clinics for veterans.

Limitations. These findings are by no means collectively exhaustive and many papers might have been missed. Other databases beyond the four major databases searched should be used in future reviews. Invasive and brain mapping techniques were not included since the scope of the review focused on non-invasive and continuous monitoring. These techniques might provide additional insights into PTSD care from a different perspective. Since the searches was focused on veterans and veteran-related problems, there might be populations that have a different outlook and experiences with PTSD, and this review had a limitation of not investigating all those populations. Despite the limitations, this narrative review along with the associated publications provide a narrative about the current research gaps in the PTSD care system and how technological interventions might help mitigate these gaps.

CONCLUSION

The narrative review based on a systematic literature review process provides the framework for a research study to analyze psychophysiological reactions of PTSD symptoms to monitor patients when they are on their own and have to deal with ill-effects of PTSD symptoms. This need is corroborated by the lack of tools to support PTSD patients, especially veterans, in the PTSD care system outside of clinical hours. Veterans deal with much severe PTSD symptoms compared to any other group within the US due to the nature of their job, along with the severity of treatments received, that are more effective on non-veterans. The research gaps highlighted in this review showcase that lack of monitoring and lack of assessment within PTSD symptoms to detect and provide interventions for veterans during their day-to-day life, should be addressed to reduce isolation and start the recovery process. Work is in progress to address this gap using a novel wearable and discrete continuous monitoring tool to detect PTSD symptoms and physiological reactions. Interventions through alerting, connection to support groups and therapeutic activities are being developed and evaluated. Such remote continuous monitoring tool can significantly improve veterans' quality of life and facilitate their reintegration into society.

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