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# Technological Advancements in Post-Traumatic Stress Disorder Detection: A Survey

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***Abstract*—It is estimated that 70 percent of adults in the United States have experienced some type of traumatic event at least once in their lives and of that, one in five will develop Post-Traumatic Stress Disorder (PTSD) as a result. Although previously thought of as a condition that affects only military combat veterans, it is a psychological condition that can affect people of all ages. PTSD can lead to depression, suicidal thoughts, and other health issues. Therefore, early diagnosis is key to not only saving lives, but also to returning them to normal. However, PTSD symptoms are often ignored or misdiagnosed. Medical professionals and researchers have sought ways to improve the reliability of traditional PTSD symptom detection and classification methods as well as increase the speed at which diagnosis can be made. Various technologies, including heart rate monitors, electroencephalography (EEG), audio recorders, and eye tracking peripherals are now being used to capture and analyze neurological and physiological data to identify markers for the condition. In this survey, we review and present issues with PTSD diagnosis and methods of symptom detection found in current literature. We evaluate the techniques employed, discuss some of the advantages and disadvantages of the technologies utilized, and recommend ways in which data collection and analysis could be improved for increased reliability of PTSD diagnosis in the future.**

***Index Terms*—PTSD, Survey, Eye Tracking, Electroencephalography**

## I. Introduction

Post-Traumatic Stress Syndrome (PTSD) is a psychiatric disorder that can occur in people who have directly experienced or witnessed a traumatic event such as a natural disaster, serious accident, terrorist act, combat, rape, kidnapping, surgery, violent personal assault, or death [1], [2]. Even events such as a motor vehicle accident, being fired from a job, or the departure of a spouse can lead to PTSD [1]. As a result, a person may have recurrent distressing memories, flashbacks, dreams, or hallucinations related to the event [1]. An individual with PTSD may also suffer from amnesia or experience difficulties in regulating emotions, alterations in arousal, intense psychological distress, or physiological reactions upon exposure to external cues related to the traumatic event [1]. In addition, the individual may feel emotional detachment and lose interest in activities once enjoyed [3].

PTSD can affect people of all ages. Almost two-thirds of children have experienced a traumatic event before reaching adulthood, most often in the form of interpersonal violence [4]. However, PTSD is often thought of as a condition that affects only combat-veterans, as it is estimated that up to 20 percent of Operation Enduring Freedom veterans and up to 30 percent of Vietnam War veterans have PTSD [2]. What is even more alarming is that an estimated 71 percent of female military personnel will develop PTSD, usually due to sexual assault within the ranks [5]. Women in general have been found to develop PTSD more often and to suffer for longer durations [1]. Other individuals with high-risk careers, such as police officers and other emergency first responders, are also more likely to develop PTSD [1], [2]. Unfortunately, those suffering from PTSD experience health declines, depression, and suicidal thoughts making early detection and treatment key to not only saving lives, but also reestablishing some normality in the lives of those that suffer from the disorder.

If PTSD is suspected, a clinician will usually conduct an interview using one of several questionnaires designed for PTSD screening. Most commonly, the Clinician-Administered PTSD Scale (CAPS) for Diagnostic and Statistical Manual of Mental Disorders (DSM) is utilized [6]. It takes a clinician approximately 60 minutes to conduct a patient interview using the questionnaire and assign a severity rating to various symptoms based on frequency and intensity [6]. Such questionnaires are usually the method for PTSD screening of troops returning from combat zones.

The accuracy of questionnaire based PTSD diagnosis has come into question for some time [7]. It is reliant upon the interviewee being honest and accurately self reporting. However, some individuals are often reluctant to respond to certain interview questions [2]. Questionnaires are also not be best suited for children who do not always verbalize their feelings or symptoms as well as adults [1]. When CAPS was utilized in one study to identify patients with PTSD, only 15% were accurately diagnosed as compared to 61% identified by medical professionals [8]. Additional psychological evaluation, psychophysiological data collection, and symptom monitoring is, therefore, still required in addition to the questionnaire results for an accurate PTSD diagnosis, making the entire process very cumbersome and subject to bias.

Automation of PTSD symptom detection and diagnosis is on the path to a faster, more reliable, more objective process. But automation is just a part of the final solution. Reliable

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diagnostic biological and behavioral markers for PTSD that can be measured consistently using readily available technologies is another part of that solution. For those markers, our initial look is to the brain and what it controls as with other psychiatric disorders. There are also psychophysicological symptoms commonly associated PTSD that can potentially aid in the diagnosis. The remainder of this paper will discuss findings from literature related to brain structural changes and physiological reactions observed in PTSD patients. We will also review current technologies and methodologies used to capture data associated with these symptoms to provide recommendations for clearing the path to the development of a rapid, reliable PTSD diagnosis system.

## II. PTSD Related Brain Structure Irregularities

As with other psychiatric disorders, researchers have looked to the brain for PTSD markers. Some studies have tied PTSD to reduced right-sided hippocampal volume [9]. The hippocampus is part of the brain associated with memory and spatial navigation, cognition and social behavior [10]. Researchers have found that stress can lead to changes in the hippocampus in both humans and animals [10]. This trend appeared to also be demonstrated in studies involving combat veterans as well as victims of severe childhood sexual abuse [9]. Some have theorized that the failure of the brain in this region may actually be the cause of symptoms experienced by those with PTSD but more research may be needed to support that theory.

Studies have shown that individuals with PTSD have elevated activity in the amygdala, the section of the brain that controls the fear response as well as memory, perception, and attention in humans [10]. The amygdala produces a chemical to help relieve anxiety and reduce the negative effects of stress [11]. Based on its purpose, it is then expected, as observed, that fearful faces and other trauma-related stimuli used in studies have been shown to activate the amygdala, and even more so in individuals with suffering from PTSD [12]. Even studies involving children show an increased amygdala volume after chronic stress in early life, especially in those children that suffered from physical abuse or neglect [10].

The frontal lobes in the brain provide functions such as working memory, goal-directed thinking, problem solving, and control of feelings and behavior [10]. Unfortunately, the frontal lobes are very sensitive to stress and reductions in grey matter volume in several regions of the frontal lobes have been observed in individuals with mental illness [10]. Volume reduction has also been observed in the insula, which is responsible for body awareness, self-conscious behavior, mediating internal stress responses and individual personality [10].

The overall trend in PTSD patients is an increased amygdala size and reduced volume in the other areas of the brain. This shift in balance in the brain and other observed abnormalities resulting from the extended periods of stress can have a range of effects on a person's body and behavior. For instance, testosterone levels have been found to decrease within twelve hours of captivity [11]. Working memory is decreased in PTSD patients, who can also experience pain and fatigue. PTSD can also result in other physiological reactivity as further discussed in the next section.

## III. PTSD Related Physiological Reactivity

PTSD related physiological reactivity is one or more bodily changes or reactions in response to stressful stimuli that resemble a past traumatic event, also known as the "fight-or-flight" response. Reactions could include heart rate changes, vascular impedance, changes in skin coloration or moisture, respiration rate changes, shaking, and other bodily responses [13]. Since these reactions are indicative of a person's emotional state, a reliable PTSD diagnosis could utilize accurate measurements of one or more of these physiological reactions upon exposure to stimuli that symbolize and resemble the traumatic event [13].

Heart rate is measured as the average number of heart beats per minute. Heart rate variability, or inter-beat interval, measures the duration of intervals between successive heart beats. It is indicative of the autonomic nervous system's ability to function, as sympathetic and parasympathetic nerves carry signals to the heart and brain for reflex functions [14]. Studies have observed an increased heart rate in individuals that have just experienced a traumatic event, as in those found in an emergency room [13]. Low heart rate variability has also been observed when the body is experiencing stress or anxiety [14]. Similar heart rate reactivity has been observed in PTSD patients in response to loud sounds [13]. Some studies [15] have observed reduced air flow or even asthma related symptoms with PTSD in addition to heart rate changes.

Skin conductance, also known as the galvanic skin response or electrodermal activity, is the electrical conductance or properties of the skin in response to sweat secretion and is an indicator of a sympathetic nervous system response [16]. Since skin conductance is affected by skin secretions, it is proportionally related to the level of activity of the sweat glands, but can also be affected by external sources of moisture [16]. A skin conductance response can occur within one to five seconds of an event but can also be unrelated to a specific event [17]. Heightened skin conductance in response to trauma related stimuli has been repeatedly observed in patients with PTSD and can be useful in the prediction or diagnosis of the condition [17].

Movements of the eyes, including how various eye muscles (see Figure 1.) contract causing a person to gaze in a particular direction or how pupils to dilate in response to stimuli, can provide insight into whether the brain is functioning properly [18]. Even how frequently a person spontaneously blinks, versus voluntarily or reflexively, and for how long, can also provide insight into brain function and nervous system integrity [18], [19]. Of the various eye movements, eye gaze is the ocular measurement most often utilized to study cognition and has even been used to analyze eye movements in infants [18]. Although not as frequently utilized, pupil dilation is another useful measurement since pupils may constrict in response to

light as well as in response to arousal as found in multiple PTSD studies [18], [20].

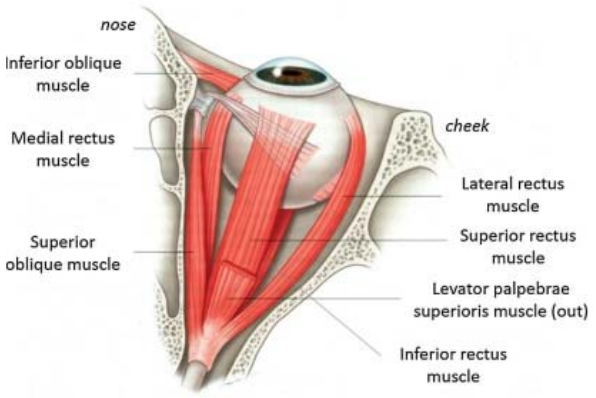


Fig. 1. Eye muscles responsible for eye movement [18]

C-reactive protein is one of a group of proteins known as acute phase reactants, which are found in the blood and produced by the liver. The protein is known to increase with an active inflammation and can be measured to aid in the diagnosis of conditions that cause such inflammation [21]. Rheumatoid arthritis, lupus, Crohn's disease, cancer, obesity, and organ and tissue damage can all cause an increase in a person's C-reactive protein level [21]. Frequently, patients with PTSD have been observed with significantly elevated high sensitivity C-reactive protein (hsCRP) levels in their blood. O'Donovan et al. [21] found in one study that veterans with PTSD had higher hsCRP than veterans that had no psychological disorders. In another study [22] involving Israeli combat veterans who were former prisoners of war, it was found that psychological and physical suffering resulted in increased hsCRP levels in those individuals.

Many Americans deal with insomnia or sleep disruptions on a regular basis. This often the case amongst those diagnosed with PTSD, who are plagued by chronic sleep disturbances that can include difficulty initiating or maintaining sleep [23], [24]. Individuals with PTSD also frequently complain of repeated trauma-related nightmares and display a considerable amount of motor activity during sleep [23]. Habukawa et al. [25] revealed that PTSD patients experience significantly more rapid eye movement (REM) sleep interruptions when compared to other individuals. Moldofsky et al. [24] also found that veterans had more REM sleep disturbances, prolonged sleep onset, delayed REM onset, less deep sleep, and more nightmares.

Some researchers have attempted to use facial expressions to interpret an individual's mental health state to support a medical diagnosis [26]. Related research thus far tends to focus on a small, distinct set of basic emotional expressions for interpretation: anger, disgust, contempt, fear, joy, surprise, sadness, and neutral [26]. The visually discernible facial muscle movements associated with each emotional expression are broken down into facial action units to support more reliable facial expression recognition [26]. Facial expression recognition and analysis studies have found that PTSD patients may be unable to express some emotions due to emotional numbing [3]. One study [3] specifically found that PTSD patients are less likely to have positive expressions and rather, maintain neutral facial expressions when presented with positive stimuli. This lack of emotional response has even been observed with adolescents in juvenile detention centers and is consistent in other sufferers of PTSD [3]. While some may argue that facial expressions are not a reliable source of data, the muscle movements required for an emotional facial response are difficult to reproduce voluntarily [11]. Studies have even found that 90 percent of people could not deliberately replicate emotional responses when asked [11].

Research [27], [28] has shown that certain speaking behavior and voice sound characteristics are closely related to the speaker's emotional state and support the identification of mental illness. When a person is depressed, neurophysiological changes can occur that can affect the laryngeal control differently than when an individual is simply expressing negative emotions [29]. For example, individuals suffering from depression are likely to have a lower fundamental frequency range and slower rate of speech relative to individuals that do not suffer from mental illness [30]. Some children who experience a traumatic event may even regress developmentally, potentially leading to a language loss [1].

## IV. Technological Approaches to PTSD Diagnosis

Researchers have utilized various technologies in their search for a better method for collecting neurological and physiological data in support of PTSD diagnosis. As technologies improve, their capabilities become more mobile, more stable, less expensive, easier to obtain, and more suitable for PTSD symptom detection.

### *A. Brain Imaging Technology*

Functional magnetic resonance imaging (fMRI) can be used to detect the levels of blood oxygenation and flow in the brain to determine the level of brain activity and detect abnormalities. Whalley et al. [31] used fMRI to investigate the cause of flashbacks in PTSD patients. Evidence of flashback association with increased activity in areas of the brain associated with the dorsal visual stream combined with decreased activity in ventral stream was present [31].

A single-photon emission computerized tomography (SPECT) scan is a nuclear imaging test that uses a radioactive substance and a special camera to create 3-D pictures. SPECT was used in one study [32] to measure regional brain blood flow in 11 combat-exposed veterans with PTSD after being exposed to combat related sounds. Activation in the middle prefrontal gyrus was observed in the veterans with PTSD as well as in the control subjects [32]. However, Liberzon et al. [32] only observed activation in the left amygdala in the veterans with PTSD, consistent with other findings and studies regarding this brain abnormality [10], [12].

### B. Heart Monitors

Heart rate and heart rate variability data can be captured by various types of heart monitors. They range from fairly inexpensive monitors in personal smart devices to more complex systems that are utilized by hospitals. These monitors have been used to detect abnormalities in heart rate and heart rate variability in response to trauma-related stimuli to support PTSD diagnosis [33]. Hauschildt et al. [33] presented positive, neutral, and negative video scenes to participants of their study, who wore heart rate monitors strapped to their chests, and captured data for later analysis that supported other studies related to heart rate changes in PTSD patients.

Instead using a basic heart monitor to collect heart rate data, an electrocardiogram (ECG) may be used to record electrical signals that travel through the heart upon each beat. It can be used to determine if the electrical signals are traveling at a normal or irregular rate. In one study, Ridout et al. [34] delivered 15 minutes of virtual reality (VR) content to veterans diagnosed with PTSD and to others that had not been diagnosed with the disorder. ECG data acquired during the study did not show a lowered heart variability in the PTSD patients viewing the VR content [34]. However, other studies [14] have shown the link between PTSD and a depressed heart rate variability following 24-hour ECG monitoring.

### C. Electroencephalography

Brain cells communicate via electric pulses, which are active even while sleeping. Electroencephalography is used to measure fluctuations in these electronic pulses, which reflect the ionic current within the neurons of the brain [35]. EEG signal processing techniques are used to extract desired features from EEG data for analysis and support the diagnosis of various diseases and disorders [35]. It has been found that PTSD is associated with decreases in low frequency power, especially in the right temporoparietal region [36]. This allows PTSD to be distinguished from mild-traumatic brain injury, which is associated with increases in low frequency power [36]. Rahamani et al. [35] were able to find features that consistently increased or decreased in particular EEG channels in only the participants diagnosed with PTSD. In another study [37], researchers were able to utilize a single EEG channel and a supervised learning process to detect the various sleep stages, which could be used to detect the REM sleep fragmentation observed in PTSD patients.

Clancy et al. [38] presented the scalp EEG topographical maps of alpha (8-12 Hz) and gamma (30-50 Hz) power averages at left and right frontal sites (see Figure 2) of study participants with PTSD, generalized anxiety disorder (GAD), and a control group. Authors [38] found that, compared with patients with GAD and healthy control subjects, patients with PTSD exhibited a broad suppression of alpha activity. Also, the authors noted that the neural activities closely coupled with frontal gamma, so the patients with PTSD also showed exaggerated frontal gamma activity [38].

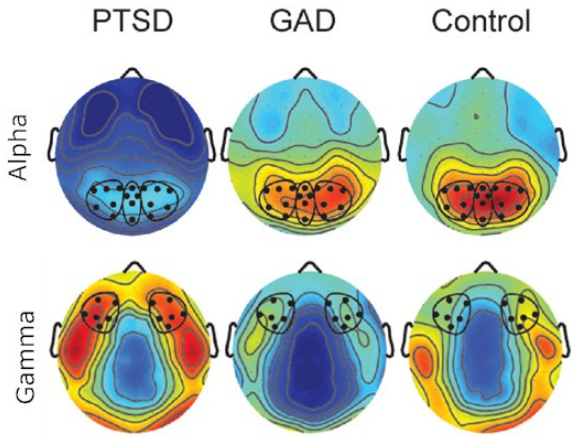


Fig. 2. EEG Topographical Maps of Alpha Powers and Gamma Powers during Standard Resting State of PTSD, GAD and Control [38].

### D. Eye Trackers

Eye trackers are designed to capture eye activity including the gaze, blink rate, blink duration, and pupil size observed as a subject follows a moving object, lines of text, or other visual stimulus with their eyes [18]. Technology for measuring and recording eye movement data has been improving, making eye trackers more portable and easier to obtain. Electrooculography (EOG) glasses, which record eye movements based on corneoretinal potential, have been used in studies to detect psychiatric disorders [30]. Head mounted eye trackers or remote eye tracking peripherals can have sampling rates from 25 to 2000 measurements per second, with faster trackers achieving temporal resolution comparable to an EEG [18]. Researchers have also worked to improve eye tracking algorithms for these devices [19]. As a result, the use of eye tracking devices have been proven as a method for identifying individuals who are suffering mental illness and other medical conditions, making it a promising technique for PTSD diagnosis [30].

A study that demonstrates the usefulness of eye tracking capability was conducted by Armstrong et al. [39]. The study involved a group of veterans that had been exposed to combat-related trauma and were diagnosed with PTSD via the Mini International Neuropsychiatric Interview (MINI) [39]. The study also included veterans exposed to combat-related trauma without a diagnosis of PTSD and healthy non-veterans as a control group [39]. The participants were asked to complete an eye tracking task in which they were asked to focus on a fixed target image [39]. Eye movements were recorded with an iView X RED-III system as disgusted, fearful, happy, and neutral facial expressions were presented on the left or right of the fixed image [39]. Authors found that veterans with PTSD would dwell longer on both the disgusted and the fearful facial expressions, relative to the happy expression, demonstrating an increased attention toward a threat in individuals suffering from combat-related PTSD [39].

### E. Skin Conductance Sensors

When a low constant voltage is applied to a person's skin, the skin conductance response can be easily measured [16]. Traditional skin conductance sensors can be somewhat costly or are often used in conjunction with other equipment, such as an EEG. Some studies have also utilized custom devices to capture skin conductance data [16].

A mobile, less expensive skin conductance sensor option, Mindfield eSense Skin Response, uses two small electrodes that can easily attached to a subject's fingers [17]. The device is relatively inexpensive, can connect to Apple or Android devices and has been used during research to collect skin conductance measurements in PTSD patients. Hinrichs et al. [17] used the device in a study involving 63 subjects at the Grady Memorial Hospital. Hinrichs successfully used eSense again in a hospital emergency department to record the skin conductance response in individuals exposed to trauma [40].

### F. Other Technologies for PTSD Detection

There are other technologies that have been used in PTSD research. A polysomnography can record brain waves, oxygen levels in the blood, heart rate, breathing, and eye movements [41]. It is the standard for sleep monitoring, providing total sleep time, sleep efficiency, and data on specific sleep stages. The technology could be used to detect signature disruptions in sleep cycles in PTSD patients [41]. Fujiwara et al. [3] used Noldus FaceReader software to process the facial expressions of a group of preschool children as they watched comedy video clips. The children were previously exposed to the Great East Japan Earthquake. The facial expression classification system found that children with PTSD more often had neutral facial expressions due to emotional numbing [3]. Audio recordings of interviews have also been utilized for speech analysis and PTSD diagnosis. Marmar et al. [42] recorded clinical interviews with combat veterans using one microphone for the subject and another for the interviewer. Of the features extracted from the participants' recordings, 18 speech features, including speed and frequency, were analyzed using a random forest probabilistic classifier to detect PTSD in the participants [42].

## V. Comparison of PTSD Detection Methods

There are advantages and disadvantages to each of the methods reviewed for collecting PTSD related data. With the exception of blood tests to detect protein levels, the methods for data collection were noninvasive. The most well-replicated physiological responses in individuals diagnosed with PTSD are increased heart rate and skin conductance responses, which have provided the most reliable data thus far [43]. Heart rate data is also very easily obtained, being already captured at most medical appointments and via many personal smart devices. However, PTSD patients are at least twice as likely as unaffected individuals to smoke, 1.5 times as likely to suffer from alcohol abuse or dependence, and 1.5 times as likely to report sleep disturbances [14]. These behavioral risks all have the ability to affect an individual's heart rate and cause low heart rate variability, which can result in many false positives in study results.

Other physiological reactions and brain structure abnormalities observed in PTSD patients may also be present in individuals with significant substance abuse or dependency issues, medication use, pre-existing disease, or obesity. EEG signals can even be affected by sleep [35]. PTSD patients are also 80 percent more likely to be diagnosed with another mental disorder such as depression, bipolar disorder, or anxiety [1]. This can and has presented problems with some research results. Many studies did not exclude individuals with behavioral or health risk factors that cause the same physiological reactions as PTSD. The similarities between PTSD symptoms and those associated with other psychological and physical conditions help make the assessment of current symptom detection and classification techniques as well as the future automation of PTSD diagnosis a challenge.

Even with careful selection of participants for future PTSD studies, the inconsistency of symptoms between each individual diagnosed with PTSD may prevent a one-size fits all approach. Therefore, integrating and analyzing multiple data sources in one system could improve the diagnosis accuracy. Beyond the use of technologies to detect commonly associated symptoms like increased heart rate and skin conductance is the potential for eye trackers. Even though eye tracking is an indirect measure of brain function, improvements in eye tracking algorithms, eye tracker portability, and equipment accessibility make it more appealing than fMRI and other technologies for mental illness detection. However, subject fatigue and distraction are limitations of eye tracking technology.

## VI. Conclusion and Future Outlook

The literature reviewed presents various brain structural abnormalities and physiological reactions to stimuli as observed in PTSD patients. It also exhibits technologies used to capture PTSD symptom data for further analysis using various algorithms and machine learning techniques. Newer technologies, like eye trackers, could be used exclusively to capture data or combined with other inputs to produce a more reliable, unbiased PTSD assessment system for those that suffer from the condition. False positives from behavioral risks must be properly accounted for in such a system.

Studies that examined PTSD amongst prior gang members, prior and current inmates, or the homeless seemed scarce but provides opportunities for future research amongst these groups. A comparison of results for other mental health conditions, such as schizophrenia and postpartum depression, could assist in identifying PTSD biomarkers that would best support automated diagnosis. Expanding research to utilize other technologies, such as electronic tattoos and smart clothing, for data collection may also prove promising in streamlining data collection and PTSD symptom observation.

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