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## Research article

## A wearable health monitoring system for posttraumatic stress disorder

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## ABSTRACT

Posttraumatic stress disorder or PTSD, a mental disorder that ensues after experiencing a shocking, life-altering, and/or traumatic event, has commonly afflicted veterans returning from military service. In this paper, we propose a system that monitors for any signs of nightmares, attempts to suppress them, or wakes the patient slowly if unsuccessful, thus improving the quality of life of those who suffer from nightmares related to PTSD. Consisting of a combination of temperature control, aromatherapy, and auditory therapy capabilities, the proposed innovation will be integrated in the form of a wearable device. The Internet of Things resource in the realm of home automation technology enables the affordable use of smart sensors as the foundation for the system. Wearable technology ties the individual into the countermeasure network and monitors for nightmare conditions. The system will have the capability of optimization through machine learning and remote management. Due to widespread diagnosis of PTSD in those exposed to trauma, the system has the potential to positively impact millions of people and reduce rates of depression and suicide.

## Introduction

Posttraumatic stress disorder, or PTSD, is defined by Webster's Medical Dictionary as "a psychological reaction occurring after experiencing a highly stressing event (as wartime combat, physical violence, or a natural disaster) that is usually characterized by depression, anxiety, flashbacks, recurrent nightmares, and avoidance of reminders of the event."<sup>1</sup> PTSD has become a common term applied to both combat veterans and those who have suffered through a variety of traumatic events in their lives. Reliving traumatic events increases stress and can be the root cause of depression and suicidal ideations. It is essential to improve the quality of life of those suffering from PTSD by creating an environment that can monitor and intervene on their behalf when they have a nightmare. This theoretical research seeks to propose a system that can automatically detect and suppress nightmares by modifying an individual's physical environment. Recent advances in microprocessing, wearable technology, home automation, and machine learning have made this environmental modification, which was once unaffordable and impractical, a realistic solution (Casselman, Onopa, & Khansa, *in press*). The National Center for PTSD (National Center for PTSD, 2017) states that "little research exists on the use of medicines to treat nightmares from trauma. The medicine with the most promise is prazosin that has been found to reduce nightmare symptoms;" however, the current side effects of prazosin

can significantly reduce quality of life (Bryan, 2016; Khachatryan, Groll, Booi, Sepehry, & Schütz, 2016).

The intent of this research is to support the mitigation of the nightmares associated with PTSD without the use of pharmaceuticals so those who suffer from the condition can focus on their therapy and recovery. For this purpose, we propose a wearable monitoring device that probes for any unusual changes in a patient's sleep that may indicate a nightmare (e.g., increased heart rate, body movements, and temperature fluctuation). If nightmares are detected, the proposed system will attempt to appease the sleeping patient via a combination of soothing aromatic therapy, cooling countermeasures, and auditory sensations. If suppression attempts fail, the system will wake the patient gently.

The remainder of this paper is organized as follows. We first present a comprehensive review of the literature on PTSD and sleep disorders with various countermeasures covering temperature controls, aromatherapy therapy, auditory therapy, gentle waking capabilities, Internet of Things (IoT), and wearable health information technology. We then propose a system with intricate features and details, and follow with a thorough discussion of the contributions of the proposed solution and its limitations, before finally concluding.

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## Background

### *PTSD and sleep disorders*

PTSD can be triggered by a variety of events that are traumatic in nature, particularly those experienced during war, natural disasters, accidents, and assaults. As a result of the increase in military activity and deployments since 2001, there has been a significant increase in the incidence and identification of PTSD in service members versus the general population. Additionally, individuals who experience trauma who are not in the military have started to be diagnosed with PTSD as well due to more comprehensive identification and classification of the disorder. According to a study done by the Department of Veterans Affairs, the lifetime prevalence of PTSD among the general population is approximately 7.8%, which rises to 13.8% in veterans who participated in Operation Enduring Freedom (Gradus, 2016). One of the primary symptoms associated with PTSD has been identified as recurrent nightmares and “increased arousal such as difficulty sleeping and concentrating, feeling jumpy, and being easily irritated and angered” (Lawrence, 2009, p. 88). Our proposed system is designed to attempt to reduce the frequency of nightmares and allow the user to increase incidence of restful sleep through the use of several proven means. Given the significant portion of the population that is experiencing symptoms of PTSD (Hoge, Riviere, Wilk, Herrell, & Weathers, 2014), the proposed system could generate a large user base within a short time period. In order to provide evidence of efficacy, it is important to delineate the methods identified for use in sleep quality modification. The identified methods for improving sleep quality are temperature modification, aromatherapy, auditory stimulus, and, as a last resort, gentle awakening of the patient.

### *Temperature*

Temperature plays an important role in comfort, both during active hours and while asleep. While it is debatable what impact temperature may play on sleep disorders such as PTSD, a 2012 study indicated that “total sleep time was a mean of 30 min longer ( $P = 0.009$ ) at a room temperature of 16 °C (60.8 °F) compared with 24 °C (75.2 °F), and sleep efficiency was significantly higher at 16 °C and 20 °C (68 °F) versus 24 °C. Patients were significantly more alert in the morning at a room temperature of 16 °C compared with 24 °C” (Valham, Sahlin, Stenlund, & Franklin, 2012, p. 515). While the study also indicated that incidence of apnea was increased as temperature was decreased, the positive correlation between a lower temperature and increased quality of sleep is evident. This would also indicate that a user who was experiencing sleep issues as a symptom of PTSD would not be inflicted with increased incidence of apnea if the condition did not already exist. Recent advent of smart home thermostats like the Nest thermostat allows for integration into the proposed IoT. This would enable a user to incorporate a smart thermostat into their system, which would trigger a decrease in temperature when the wearable technology indicated restlessness or an increase in heart rate. In doing so, the system would ensure that the environment is more conducive to restful sleep, with the hope that it would ease the user’s stress during sleep and prevent an active nightmare from perpetuating.

### *Aromatherapy*

Aromatherapy has been used for hundreds of years in homeopathic medicine, and while it is not scientifically recognized as a means of healing, it has been used widely in relaxation therapy and in state association. The impact of aromatherapy and the associated biological response have been described by Linda Buck, the 2004 Nobel Prize laureate in Physiology or Medicine (Buck, 2005), who found that, “the responses to an odor are neurologically transmitted to the olfactory bulb in the brain. There, the information from several olfactory

receptors is combined, forming a pattern that is perceived as a distinct odor in multiple areas in the cerebral cortex and the limbic system. Even though nasal receptors are quite specific, human beings are able to differentiate up to 10,000 odors through a complex sensory-somatic cascade that instantaneously activates the autonomic nervous system, memory, and emotion through the amygdala and other limbic structures” (Butje, Repede, & Shattell, 2008, p. 48). This solidifies the biological basis for the use of aromatherapy as a means of stress and anxiety relief, particularly when used to induce a relaxed state during sleep. The study continues to explain that “olfactory stimulation causes immediate physiological changes in blood pressure, muscle tension, pupil size, blink magnitude, skin temperature, skin blood flow, electrodermal activity, heart rate, brain wave patterns, and sleep/arousal states” (Kuroda et al., 2005, p. 107). This implies that the use of essential oils in an oil diffuser could feasibly be used to alter sleep state and induce relaxation in a user who is experiencing symptoms of PTSD. The proposed system would incorporate an oil diffuser connected to a smart outlet that could be triggered when the user’s heart rate or activity level is increased, indicating periods of restlessness. Several sources suggest that a combination of sandalwood, bergamot, and lavender can be used to induce relaxation as well as to treat insomnia, though the user would be free to select the oil mix that works best for their situation. With this embedded automatic oil diffuser, the system will be able to more fully address the symptoms of PTSD and increase the likelihood of the patient’s restful sleep.

### *Auditory therapy*

Music and sounds are a constant in daily life. Sounds are used in communication and observation, and to instigate different moods. This is evident in the movie industry, for instance, where music is used to set the mood for different scenes. For example, if a director were to use a whimsical tune during a serious moment, the viewer might not recognize the fact that it is serious and would not be as involved in the plot. The designed system aims to incorporate music and sound into the treatment plan to leverage their profound impact on mood and relaxation. In a randomized controlled trial comparing one group that was subjected to music during sleep and one that was not, Lai and Good (2005, p. 239) found that in a music group, “there were significant improvements, with a small to medium effect size in both global and perceived sleep quality, sleep latency, sleep duration, sleep efficiency and daytime dysfunction.” Though the study focused on adults over 60, it can be presumed that the results would hold on a younger population, given the fact that sleep cycle and body rhythm is a more or less a constant factor throughout life. The proposed system would incorporate music through using a smart outlet, or could be ported directly through the application which could be amplified by an external Bluetooth-enabled speaker. Music would enable the user to increase their sleep quality and duration, thereby alleviating some of the symptoms of PTSD without the use of pharmaceuticals. The type of music or ambient noise played could be customized by the user depending upon what was perceived to work and what did not work. The system could be triggered to change the music depending on whether the patient’s restlessness has ceased. If, despite all these interventions, the proposed system still fails to alleviate the patients’ restlessness while asleep, he or she could be gently awoken to avoid further nightmares through a variety of means.

### *Gentle waking*

As a final means of modifying the user’s sleep, it is proposed to wake the user up using gentle means if the user remains restless or their heart rate is elevated for an extended period. This would only trigger in rare instances with the idea that it would enable the user to wake from sleep that is largely unbeneficial to their condition or would not contribute to increased alertness while awake. In order to allow the user to wake

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