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# Do you copy? Post-traumatic Stress Disorder, Auditory Processing, and Heart Rate Variability

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# Do you copy? Post-traumatic Stress Disorder, Auditory Processing, and Heart Rate Variability

by

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Abstract

Self -report measures used in PTSD research have the potential to limit the degree of symptom severity in military veterans, especially as there is often underreporting in this population (Kline, Falca-Dodson, Susner et al., 2010). Polyvagal Theory provides a framework assessing if physiological measures can tap into PTSD Symptomology (Porges, 1995). It is therefore hypothesized that lower scores on auditory processing tests will be positively correlated with higher scores on Stress and PTSD measures. Additionally, it is thought that lower scores on auditory processing tedts as well as higher scores on PTSD and Stress Measures will be positively correlated with decreased Heart Rate Variability. After answering a series of survey questions, participants completed a hearing test as well as Auditory Processing tests while having their heart rate monitored; from that, heart rate variability was computed and several Hierarchical Linear Regressions were performed, controlling for Age, Sex, Branch of Service, and Active Duty Status. No statistically significant relationships were found between PTSD, heart rate variability, and auditory processing measures. Data collection was stopped early due to COVID-19, which limited statistical power for analyses. The goal of this research is to determine a way to increase the accuracy of PTSD diagnosis.

*Keywords*: Polyvagal Theory, PTSD, Heart Rate Variability, Auditory Processing

Do you copy? Post-traumatic Stress Disorder, Auditory Processing, and Heart Rate Variability

Stress and Post-traumatic Stress Disorder (PTSD) are significant topics in the Armed Forces of the United States because of the nature of the Profession of Arms. PTSD, a mental illness that occurs after experiencing a traumatic event, is prevalent among members of the United States Armed Forces, with approximately 8 in 100 veterans having the disorder (American Psychiatric Association, 2013; "PTSD", 2019).The Diagnostic and Statistical Manual of Mental Disorders, 5th edition (DSM-5) cites the following key features for diagnosis of PTSD: Exposure to a traumatic event as either a direct experience or witness, intrusive occurrences such as flashbacks and dreams of the event, avoiding reminders of the event (including environment, people, and thoughts), negative mood and cognitions that begin or increase after the event, changes in activity and reactivity (hypervigilance, sleep disturbance, exaggerated startle response, and difficulty concentrating) (Jeste et al., 2013).

It is important to note that to be diagnosed as PTSD, these symptoms cannot be attributed to medication, alcohol, or another condition. Features of PTSD are common in other disorders, and it is important to distinguish between them and PTSD itself. One such example is Acute Stress Syndrome. It has many of the same criteria for diagnosis as PTSD, apart from duration of symptoms: Acute Stress symptoms occur from 3 days up to a month after the traumatic event (Jeste et al., 2013). If the symptoms persist after one month, the diagnosis then becomes PTSD. Additionally, given the nature of military service, it is important to consider Traumatic Brain Injury (TBI). Traumatic accidents and explosive blasts are a few examples of how PTSD symptoms may feature when a brain injury occurs. The main distinguishing criteria focuses on presentation of symptoms: re-experiencing the traumatic event and avoidance are more characteristic of PTSD, whereas confusion and persistent disorientation are more characteristic of TBI (Jeste et al., 2013).

Cumulative stress plays a role in PTSD development, both before and after a traumatic experience (Brewin et al., 2000). Given the nature of the profession of arms, there is the potential for increased exposure to trauma, especially in combat arms operational specialties, such as infantry, armor (tanks), and artillery (Pike, n.d.). In the combat arms service specialties, there are greater instances of combat severity, which has been associated with greater occurrence of PTSD and the persistence of the symptoms (Green, Grace, Lindy, Glesser & Leonard, 1990; Koenen, Stellman, Stellman, & Sommer, 2003; Roy-Berne et al., 2004; Jankowski, Schnurr, & Adams et al., 2004). It has been reported that as many as 86% of the service members in Iraq know someone who was seriously injured or killed, 75% having a member of their unit killed, 68% seeing dead or seriously injured Americans, and 51% handling or uncovering human remains (Hodge et al., 2004). Medical advances have allowed for greater post-injury survival. However, they have also made it possible for a greater chance of experiencing trauma, not only from being injured, but from seeing the suffering and injury of others (Litz, 2007). It is important to note that the above statistics are from a single conflict in U.S. Military History, the war in Iraq; research has shown it is more likely combat exposure rather than deployment alone which contributes to the development of PTSD, as trauma exposure is necessary for a PTSD Diagnosis (Smith, Ryan, & Wingard et al., 2007).

Part of what makes PTSD and other trauma difficult to treat is an absence in understanding of the totality of physiological responses to threats in the environment (Porges, 2017; Volchan et. al, 2017). In the military population, the prevalence rate in 2010 was reported to be 2-17%, compared to 3.5% prevalence in a civilian population (Richardson, Fruch, &

Acierno, 2010; Jeste et al., 2013). One of the main means of determining if a person has significant PTSD symptomology is a self-report measure, the PTSD Checklist 5th Edition (PCL-5) (Jeste et al., 2013; Blevins et al., 2015). This measure is often used in conjunction with clinical interviews to create a more accurate clinical picture. However, there are problems with both measures.

Currently, self-report measures are the chief method of measuring PTSD symptomology. One of the issues with Self-report measures is response bias, which can occur for several reasons, from misunderstanding what items are trying to measure or socially desirable responding (Rosenman, Tennekoon & Hill, 2011). Socially desirable responding occurs when a participant responds in a way that will paint them in a favorable light, even if the survey is anonymous (Rosenman et al., 2011). Socially desirable responding prevents a researcher from gaining accurate measurements of the phenomena, trait, or symptoms in question. It is also possible that self-report measures for PTSD act to limit the variation in reported levels of distress, especially in research with military populations, making symptom measurement and treatment more difficult. (Kline, Falca-Dodson, Sussner et al., 2010). Adding one or multiple biobehavioral measures, such as heart rate variability or auditory processing, to a self-report measure can help to better indicate true symptom severity.

In addition to problems with responding in a manner that is desirable within the microcosm of the Armed Forces, the issue of treatment assessment can arise. Sometimes, a recalibration bias occurs, known as “response shift bias” (Rosenmann et al., 2011). Response shift bias is present when there is a change in the frame of reference that a respondent uses to answer items in self-report measures, which can be due to the treatment, causing confounding. The response shift could also be a result of a respondent becoming more familiar with concepts and changes in estimation of personal functioning, further reducing clarity on if a treatment is effective (Howard, 1980; Sprangers and Hoogstraten, 1989). Combined with socially desirable responding, it becomes increasingly difficult to treat PTSD..

Additionally, there is a stigma surrounding mental illness in general that is even greater within the Armed Forces. In a predominately (84%) male fighting force (Military One Source, 2014), mental illnesses like PTSD are considered a weakness (Holtz, 2015), and should be concealed. This view has led to phrases such as “man up” or “ranger up”, in addition to decreased reporting of symptoms. Under-reporting of symptomology and treatment seeking could also be due to the effects on a service member’s career (Johnson & Agius, 2018; Young, 2016). If mental illness appears on their record, service members can be held back from promotions, certain duty stations, and specialty schools such as Ranger School, Navy Seal Training, or Pararescue School, as well as receive discharge types other than honorable, which can effect post discharge benefits such as G.I. Bill for education and Veteran’s Affairs Health Care (Young, 2016).

## Polyvagal Theory

The Polyvagal Theory, first proposed by Porges in 1995, integrated the role of neural mechanisms as a part of the regulation of Biobehavioral Processes. Reactions, whether behavioral or psychological, are dependent upon physiology. Including this neural component could allow for the development of more testable hypotheses (Porges, 2007). Polyvagal Theory comes from psychophysiology, a means of using physiological measures such as heart rate variability to help understand psychological processes that are difficult to understand by observing behavior alone (Porges, 2007). Polyvagal Theory is different from pure psychophysiology in that it includes a neural component. It details functional and structural linkages between control of striated muscles in the face as well as smooth visceral muscles, as a means of engaging in defense strategies (Porges, 2007). This Social Engagement System is one of the two vagal circuits that comprise the Polyvagal system, the other being an ancient circuit primarily involved in defense ((Porges & Lewis, 2010); Williamson et al., 2015).

The Social Engagement System, the second vagal circuit to evolve in mammals, makes communication between the brain, face, and rest of the body possible, allowing humans and other mammals to interact with each other through gestures, vocal inflections, and facial expressions (Williamson et al., 2015). Both vagal systems working together allow for humans to feel safe, demonstrating two key features: the body can restore itself and grow, and the nuclei of the brainstem regulate the myelinated portions of the vagus nerve that control the muscles of the face and head (Williamson et al., 2015). The health of both vagal systems is important as the autonomic nervous system, emotion, and cognition share brain anatomy (Williamson et al., 2015). The vagus nerve has sections that are either wrapped in a myelin sheath or without, and the myelinated portions are depended upon by the Social Engagement System (Porges, 2007; Porges & Lewis, 2010). This myelinated portion serves to create calm states by suppressing both the Hypothalamic-Pituitary-Adrenal Axis (HPA) and sympathetic nervous system influence upon the heart (Porges, 2007).

Sympathetic Nervous activity is responsible for the fight or flight response, but there is another response that can occur: freezing. Also called immobilization, this response is controlled by unmyelinated portions of the vagus nerve, and is the most primitive response system (Porges, 2007). There are progressing levels of complexity, starting with the immobilization response, followed by the mobilization response, and at the top of the progression, is the inhibition of the sympathetic nervous system's effects on the heart and the HPA (Porges, 2007). Both immobilization response and mobilization are inhibited by the higher order HPA and heart suppression, but when that higher order system is not functioning, the mobilization response takes over, and the immobilization response takes over if the mobilization response is non-functioning (Jackson, 1958). Jackson proposed that this dissolution reaction occurs as a result of injury or illness, but in Polyvagal Theory, it is used to explain how humans respond adaptively to safe or unsafe events (Porges 2007, 2017). This response by a process called neuroception.

Neuroception is different from perception in that it is outside of cognitive awareness. When an environment is perceived as safe, there are two defining functions that are observed; visceral homeostasis is maintained efficiently while allowing for growth and brainstem nerve cells are integrated with the nerves of the face and head (Porges 2007). This integration controls listening, eye gaze, and the ability to distinguish meaning from vocal tone (Porges, 2007). This integration also allowed for the source nuclei to shift to the nucleus ambiguus from the dorsal motor nucleus, creating the paths that regulate control of striated muscles in the head and face; this makes it possible to explain a variety of social, emotional and communication behaviors and deficits (Porges, 2007). Neuroception is the process which either enacts or disengages the defenses of the social engagement system by shifting autonomic state, resulting in changes in Heart Rate Variability, digestive functioning, and startle reflexes (Porges, S and Porges, S.W, 2017; Williamson, Porges, Lamb & Porges, 2015). For example, when a situation is perceived as dangerous, Heart rate increases while middle ear muscle function decreases to hear extremely low or high frequency sounds, such as human screams or predator sounds (Porges & Porges, 2017).

**Anatomy of the Hearing System as Connected to Polyvagal Circuit**

Part of this social engagement system is the auditory system. Included in a branch of the face-heart neural pathway are the nerves that control the muscles of the middle ear (Porges & Lewis, 2010). These muscles are responsible for the tightening of the ossicular chain. The tightening of this chain allows for the detection of a low amplitude high frequency airborne sound (like a human voice) in an environment primarily composed of low frequency loud sounds (such as a busy street) (Porges & Lewis, 2010).

There are five branches of the Facial Nerve in the Temporal Bone. The Temporal Bone helps protect the Middle and Inner ear (Barral & Croibier, 2009). There are two branches of particular interest concerning hearing and the Polyvagal Theory: a branch that connects to the stapedius muscle in the middle ear and the Auricular branch (Barral & Croibier, 2009). The stapedius muscle is key in the tightening of the ossicular chain (Porges & Lewis, 2010). This chain is comprised of the malleus (hammer), the incus (anvil), and the stapes (stirrup) (McFarland, 2009; See Appendix A for reference). According to the Polyvagal theory, the tightening of this chain allows for humans to extract higher frequency sounds (like the human voice) from lower frequency background sounds (Porges & Lewis, 2010).

The Auricular branch of the Facial Nerve that shares a path with the Auricular branch of the Vagus nerve (Barral & Croibier, 2009). This Vagus and connecting Facial branch not only activates the skin of the outer ear, but part of the surface of the tympanic membrane (ear drum) as well (Barral & Croibier, 2009).

**The Heart and Polyvagal Response.**

The heart is strongly influenced by the vagus nerve; when there is a strong signal to the heart's sino-atrial node, a vagal brake is activated to prevent heart rate from increasing too much

(Porges, 2007). The brake can be removed to activate the fight-or-flight response, or maintained to promote social engagement (Porges, 2007). The muscles of the face and head are striated and are innervated by several cranial nerves that branch and connect to the vagus nerve, serving not only to increase engagement, but to filter out distractions (Porges, 2007). It has been suggested that because of the connection between these engagement systems that in individuals with autism and other disorders, there will be difficulties in eye contact, picking out human voices from background noise and recognition of facial expressions (Porges, 2007). PTSD is one such disorder in which there are difficulty in recognizing social cues and expressing social behavior (Porges, 2007). The vagus is not the sole structure responsible for issues with the social engagement system, nor emotional control, but part of a neural circuit (Porges, 2007). The Polyvagal Theory seeks to link changes in heartrate with differences in different variables, such as psychological, behavioral, and clinical variables (Porges 2007). As explained by Thayer and colleagues, "The heart and brain are connected bi-directionally. Efferent outflow from the brain affects the heart and afferent outflow from the heart affects the brain" (Thayer et. al, 2012).

***Heart Rate Variability.***

Heart rate variability (HRV) examines the differences between individual inter-beat intervals. Not only a measure of heart function, it is thought that heart rate variability can provide information about how the brain interacts with the heart in terms of adaptation to complex environments (Thayer et al., 2012). The Autonomic Nervous system (ANS) and its subdivisions, the Sympathetic (SNS) and Parasympathetic Nervous System (PNS), control heart rate. The SNS allows for a decrease in HRV, whereas the PNS allows for increases in HRV. These ANS subdivisions have the opposite effect on Heart rate: the SNS increases Heart rate while the PNS decreases Heart Rate. (Tarvainen et al., 2018). Put another way, the SNS increases the inter-beat interval while the PNS decreases the inter-beat interval (Thayer et al., 2012). There are other measures of heart rate variability which indicate the Vagus nerve is exerting its influence on the heart: High Frequency (HF) is one such measure of Heart Rate Variability, and the Root Mean Square of Successive Differences (RMSSD) is another. HF measures heart rate variability in the frequency domain whereas RMSSD measures HRV in the time domain (Tarvainen et al, 2018). Both of these measures are key in supporting the Polyvagal Theory, as they are indicators of vagal tone.

### ***Cumulative Stress***

Cumulative stress plays a role in PTSD development, both before and after a traumatic experience (Brewin et al., 2000). The more trauma a person has experienced, the more likely it is they will develop PTSD, and therefore more likely to perceive a situation as dangerous. Based on Polyvagal Theory, a situation that is perceived as dangerous or stressful would trigger the Polyvagal System, resulting in changes in Heart Rate (and Heart Rate Variability) as well as Auditory Processing while responding to a stressful situation. (Porges & Porges, 2017).

The major aim of this study is to determine if heart rate variability and auditory processing can be used as supplemental measures in line with current self-report and interview methods. Polyvagal theory suggests that these two physiological measures could be useful in this endeavor, as a means of connecting physiological responses to psychological processes during stressful or traumatic situations. Having additional indices of stress response would allow for more accurate diagnosis of PTSD.

It is therefore hypothesized that higher levels of PTSD will predict poorer auditory processing . It is hypothesized that higher levels of PTSD as measured by the PCL-5 PTSD checklist will predict poorer scores on the Filtered Words Test of the SCAN-3A. It is also hypothesized that there will be an association between lower Heart Rate Variability and lower scores on auditory processing tests. Greater cumulative trauma will be associated with lower scores on auditory processing tests.

## Method

### Participants

Participants were recruited both through the SONA Research System and the Military and Veteran Resource Center. Flyers were posted around campus, in addition to electronic campus updates and announcements in psychology courses. Participants in this study were both Active Duty and Veteran Students at the University of North Florida that are 18 years old or older. Age in this population is expected to be higher than the general population of the university, and while there are both males and females in the veteran student population, much like the Armed Forces, the sample is expected to be predominately male. The goal was to have 50-60 participants, so that in the event of attrition between Session 1 and Session 2, there would be at least 43 participants. This number was determined by conducting a power analysis using G*Power (Kiel, Faul, Erdfelder, Lang, & Buchner, 2007), in order to have an 80% chance of finding a medium effect size ($f = .35$) at a statistically significant level ($p < .05$). This recommendation is line with the recommendations for good practice set out by Lancaster GA, Dodd &Williamson in 2004 in the Journal of Evaluation in Clinical Practice that for Correlations, Multiple Regressions, and repeated measures ANOVA/ANCOVA, a sample size of at least 30-50 participants is recommended.

### Measures

**Demographic Variables of Interest.**

Demographics are also of interest, especially when concerning military populations. In addition to gender and age, Branch of Service, Occupation in Service, Time in Service, Mission Type were also be examined. These factors can affect coping with stress, as well as trauma history. There was a total of 38 participants with an average age of 31.87 years of age. Predominately identifying as white (65.8% of the sample), the majority of the sample serves or had served in the U.S. Navy (47.4%), followed by the U.S. Army (23.7%). Most of the participants were veterans (78.9%) and had not received a PTSD diagnosis, serving an average of 9.46 years in service (SD= 6.33). The majority of the participants had deployed at least once (68.4%) to a combat zone (60.5%). More in-depth demographic information can be found in Figures 3-6.

**SCAN-3A for Adults and Adolescents.**

The SCAN-3A by Pearson (Keith, 2009) measures aural processing ability by presenting stimuli to a participant through headphones. Because the tests within the SCAN-3A battery effectively measure Aural Processing for those individuals with undamaged hearing, a hearing test was conducted, using the Oscilla-310 Audiometer, prior to the Start of the SCAN-3A. There are several measures of auditory processing in this test, but the two of interest in this study are the Filtered Words Test and the Auditory Figure-Ground Test.

The Auditory Figure-Ground Test asked participants to identify muffled words, playing 20 words in the right ear, then 20 words in the left ear, and the subject identifies the words. The Filtered Words Test had participants report single syllable words that are presented over background noise, playing 20 words in the right ear, then 20 words in the left ear, and the subject identifies the words. Designed to determine a person’s ability to process distorted speech, the words were low passed through the background noise filter which as a frequency of 750 Hz, which is within the frequency range of 500-4000 Hz that is the band of perceptual advantage in humans, a component of the Social Engagement System detailed in the Polyvagal Theory (Porges, 2007). According to the instruction manual for administering the SCAN-3A, the Filtered Words Test is both reliable and valid, and so too is the Figure Ground Test.

Both the Figure-Ground Test and Filtered Words Test were found to have interrater reliability of between .98 and .99 (Keith, 2009). Overall, for composite scores, both Figure-Ground and Filtered Words had a test-retest reliability value of 0.78 (Keith, 2009). A corrected stability coefficient of .68 was found for the Figure-Ground at 0 Db. For the Filtered Words Test, a corrected stability coefficient of .59 was found (Keith, 2009). A Fischer's Z transformation, a measure of internal consistency, was conducted for both the Figure-Ground Test and Filtered Words Test. A Fischer's Z of .76 was found for the Figure-Ground test, and for the Filtered Words Test, a Fischer's Z of .91 was found (Keith, 2009). These measures are related to the Polyvagal Theory in that the ability to complete these tasks is dependent upon the tightening of the ossicular chain in the ear that allows for the discrimination of speech from background noise and the detection of low frequency sounds, and this tightening is governed by the Vagal System (Porges, 1995; 2007). This allows for Social Engagement, and under the Polyvagal Theory, is related to Heart Rate Variability.

**Heart Rate Variability.**

Electrocardiogram data was collected with an eMotion FAROS-180 sensor. The eMotion FAROS-180 was a non-invasive means of measuring differences in heartbeat peak intervals, often called R-R intervals. The data collected with the eMotion FAROS-180 units was then inspected and cleaned for analysis using Kubios software from the Kubios Oy Company. Heart Rate Variability (HRV) was calculated using Kubios as well. Artifacts were assessed and removed using the Automatic Artifact Correction in Kubios. This Automatic Artifact Correction detected differences in successive R-R intervals from a time series by comparing every beat interval to the average local R-R interval, and when the beat exceeded that average, it was considered an artifact (Kubios, 2019). Artifact correction is important so as not to distort Heart Rate Variability analysis: Artifacts included extra beats, misaligned beats, and ectopic beats (Kubios, 2019; Task force, 1996). Following the procedures laid out by Porges in 1985 (Porges, 1985), R-R intervals give an indication of the function of the Autonomic Nervous System (ANS) (Minissan et al, 2014; Pole, 2007; Sztajel et al, 2004). R-R intervals can be used to calculate Heart Rate Variability in both time and frequency domains. High Frequencies (HF) is one frequency domain measure of Heart Rate Variability, and the Root Mean Square of Successive Differences (RMSSD); both are indicators of vagal tone and its influence on the heart (Tarvainen et al, 2018; Porges, 1995, 2003, 2007). Heart Rate variability is also a measure of the Vagal System on the heart, and decreased variability can be indicative of both Post-Traumatic Stress Disorder (PTSD) and higher levels of stress (Porges, 2009; Tan, Dao, Farmer et al, 2011).

**PTSD Checklist.**

The PTSD Checklist, the PCL-5, is the most current self- report measure for PTSD. Developed in 2013 by Weathers and colleagues, it measures the 20 symptoms of PTSD that are noted in the Fifth Edition of The Diagnostic and Statistical Manual of Mental Disorders (DSM-5) (Weathers et al., 2013). The items are rated from zero to four using a Likert-Type Scale, 0= Not at all, 1= A little bit, 2= Moderately, 3= Quite a bit, 4= Extremely. There are three ways to administer the PCL-5 Checklist, and in this instance, it is being administered with only brief instructions and the items. While the results of this measure are to be interpreted by a clinician, there are multiple ways in which it can be scored. A total score composed of summed responses across the 20 items in the checklist which indicates symptom severity will be used in this study, where a score of 33 or more was the suggested total score for a PTSD Diagnosis (Weathers et al., 2013). This measure has been found to be reliable, with internal consistency ($\alpha$ =.94), as well as convergent validity (*rs*= .74-.85) and discriminant validity (*rs*=.31-.60). It also had test-retest reliability (*r*= .82) (Blevins et al., 2015; Weather et al., 2013). In this sample, the PCL-5 had a Cronbach's Alpha of 0.943, and a range of 56.

**Brief Trauma Questionnaire (BTQ).**

The Brief Trauma Questionnaire (1999), a measure of trauma history, was derived from the Brief Trauma Interview (BTI, 1995) by its authors (Schnurr et al., 1995; Schnurr et al. 1999). It is a ten item self-report measure with a Kappa Coefficients (reliability) ranging from 0.6-1.00, and 8 out of the 10 items having a Kappa coefficient greater than or equal to 0.74. While originally developed under DSM-IV criteria for traumatic exposure, one of the criteria (subjective response) has been eliminated in the DSM-5 reclassification of PTSD, leaving the life threat/serious injury criteria intact (PTSD, 2017). Used to determine if an even meets Criteria A and/or the types of Criteria A events experienced, the items are answered using a yes/no format. Criteria A is met if respondents answer "yes" to life threat or serious injury for items 1-3 and 5-7, life threat for item 4, serious injury on item 8, and endorsing the "has this ever happened to you?" part of items 9 and 10. This measure is included as previous trauma can affect Heart Rate Variability and Auditory Processing, according to the Polyvagal Theory (Porges 1995, 2003, 2007).

## Procedures

Before the study began, it was reviewed by the University of North Florida Institutional Review Board to ensure the welfare, rights, and privacy of the participants, and was approved.

This study was a within subjects repeated measures design. As such, there were two testing sessions given 1 month apart, give or take seven days. Session 1 took approximately an hour, with Session 2 taking approximately 1 hour as well. Total participation time was around 2 hours.

For Session 1, Participants met Researchers by the elevators on the third floor of the Psychology building (Building 51) and were escorted to the lab space. After the researcher gave a brief overview of the study, the participant was given an Informed Consent Document. After being given time to read the document and ask questions, if they chose to participate, signed the document in front of the researcher. Next, the participant completed a Qualtrics survey, comprised of several measures (two of which are the PCL-5 and BTQ, as well as demographic, health, and military questions). After reaching a completion screen and notifying the researcher, the participant attached heart rate sensors with the help of the researcher. A 2-minute baseline was taken before and after the Audiometer/SCAN-3A. Several other measures followed, as this analysis of PTSD, the Polyvagal Theory, and hearing is part of a broader study. After completing these tasks, the participant scheduled the second session approximately one month from the initial session.

For Session 2, participants completed the procedures of Session 1, but the Qualtrics Questions did not have the demographic questions included. After the completion of this second session, Participants were given a $20 gift card as compensation and thanked for their time. Additionally, participants were given course extra credit through their participation in SONA. Any questions a participant had were answered in a debriefing before their departure.

Given the nature of this study, it is possible that participants felt distressed. At both the initial session and session 2, as part of the exit procedure, participants were reminded that if they were feeling distressed, there were several resources on campus available to them to help alleviate those feelings. They were provided with directions to the University of North Florida Counseling Center (Building 2, Room 2300), as well as directions for accessing the Supporting Our Students Program (SOS), through the Office of the Dean of Students (Building 57, Suite 2700).

## RESULTS

Analyses were conducted in 2 parts. First, correlations were conducted to determine if multicollinearity existed between demographic variables, predictor variables, and criterion variables. Demographic variables included age and sex, as well as military demographic variables such as Branch of Service, Active Duty Status, paygrade, deployment status, role type (combat, combat support, combat service support), mission type (peacekeeping vs. Combat). Predictor variables included PCL-5 sum scores, Heart Rate Variability, and Brief Trauma Questionnaire Total Score, while the criterion variables were the auditory processing measures (Auditory Figure-Ground and Filtered Words total scores). While this yielded some significant correlations (summarized in Table 1), they are consistent with research and military structural operations. A majority of participants had deployed (68%), and of those that did deploy, 60% deployed to a combat zone. Branch of Service, Age, Sex, and Active Duty Status were statistically controlled for, as the sample was predominately comprised of U.S. Navy Veterans that were 31.87 years old on average. Sex was controlled for as well, since the make up of the Armed Forces as a whole are predominately male, even though the sample had roughly the same number of male and female participants.

Secondly, hierarchical linear regressions were conducted to test hypotheses. Step One included force entering characteristics such as age, sex, active duty status, and branch of service, and Step

Two included predictor variables (PCL-5 sum score, Heart Rate Variability, and BTQ Total scores) and criterion variables (total scores on Auditory Figure-Ground and Filtered Words).

***PTSD and Auditory Processing***

*Auditory Figure-Ground*

Step 1 showed that variance accounted for in performance on the Auditory Figure-Ground Test ($R^2$) by Age, Sex, active duty status, and branch of service was 0.066 (adjusted $R^2$= -0.051), which was not significantly different from zero ($F_{(4,32)}$= 0.564, *p*= 0.691). In Step 2, PCL-5 sum scores were entered into the regression model, and the variance accounted for on performance on the Auditory Figure-Ground Test was ($R^2$= 0.083), 8.3% of the variance in Auditory Figure-Ground scores as predicted by PCL-5 scores after controlling for the covariates, which was not significantly different from the amount of variance predicted by the covariates ($F_{(5,31)}$= 0.451, *p*= 0.809). Standardized Regression Coefficients, t values, and *p* values for Step 2 are reported in Table 2 below.

*Filtered Words*

Step 1 showed that variance accounted for in performance on the Filtered Words Test ($R^2$) by Age, Sex, active duty status, and branch of service was 0.154 (adjusted $R^2$= 0.049), which was not significantly different from zero ($F_{(4,32)}$= 1.459, *p*= 0.238). In Step 2, PCL-5 sum scores were entered into the regression model, and the variance accounted for on performance on the Filtered Words Test was ($R^2$= 0.169), after controlling for covariates: 16.9% of the variance in Filtered Words scores was predicted by PCL-5 scores after controlling for covariates, which was not significantly different from zero ($F_{(5,31)}$= 1.264, *p*= 0.304). Branch of Service was a statistically significant predictor of Filtered Words score (β= 0.349, t=2.063, p=0.0048). Standardized Regression Coefficients, t values, and *p* values for Step 2 are reported in Table 3 below.

***Heart Rate Variability and Auditory Processing***

*Filtered Words- RMSSD*

Step 1 showed that variance accounted for in Heart Rate Variability- RMSSD ($R^2$) by Age, Sex, active duty status, and branch of service was 0.225 (adjusted $R^2$= -0.013), which was not significantly different from zero ($F_{(4,13)}$= 0.945, $p$= 0.469). In Step 2, Filtered Words Total Scores were entered into the regression model, and the variance accounted for ($R^2$) was 0.235, after controlling for covariates: 23.5% variance in Filtered Words Scores as predicted by RMSSD heart rate variability after controlling for covariates was not significantly different from the regression model composed of the covariates ($F_{(5,12)}$ = 0.737, $p$= 0.610). Standardized Regression Coefficients, t values, and *p* values for Step 2 are reported in Table 4 below.

*Filtered Words- HF*

Step 1 showed that variance accounted for in Heart Rate Variability- HF ($R^2$) by Age, Sex, active duty status, and branch of service was 0.225 (adjusted $R^2$= -0.013), which was not significantly different from zero ($F_{(4,13)}$= 0.945, $p$= 0.469). In Step 2, Filtered Words Total Scores were entered into the regression model, and the change in variance accounted for ($R^2$) was 0.278: 27.8% of the variance in Filtered Words Scores as predicted by HF heart rate variability after controlling for covariates was not significantly different from the regression model composed of the covariates ($F_{(5,12)}$ = 0.923, $p$= 0.499). Age was almost a statistically significant predictor of Filtered Words score (β= 0.482, t=1.787, p=0.099). Standardized Regression Coefficients, t values, and *p* values for Step 2 are reported in Table 5 below.

*Auditory Figure-Ground- RMSSD*

Step 1 showed that variance accounted for in Heart Rate Variability-RMSSD ($R^2$) by Age, Sex, active duty status, and branch of service was 0.358 (adjusted $R^2$= 0.161), which was not significantly different from zero ($F_{(4,13)}$= 1.815, $p$= 0.186). In Step 2, Auditory Figure-Ground Total Scores were entered into the regression model, and the change in variance accounted for was ($R^2$) 0.369: 36.9% of the variance in Auditory Figure-Ground Scores was predicted by RMSSD heart rate variability after controlling for covariates was not significantly different from the regression model composed of the covariates ($F_{(5,12)}$ = 1.406, $p$= 0.290). Active Duty Status was a statistically significant predictor of Filtered Words score (β= 0.585, t=2.303, p=0.040). Standardized Regression Coefficients, t values, and $p$ values for Step 2 are reported in Table 6 below.

*Auditory Figure-Ground- HF*

Step 1 showed that variance accounted for in Heart Rate Variability- HF ($R^2$) by Age, Sex, active duty status, and branch of service was 0.358 (adjusted $R^2$= 0.161), which was not significantly different from zero ($F_{(4,13)}$= 1.815, $p$= 0.186). In Step 2, Auditory Figure-Ground Total Scores were entered into the regression model, and the change in variance accounted for ($R^2$) was 0.481: 48.1% of the variance in Auditory Figure-Ground Scores was predicted by HF heart rate variability after controlling for covariates was not significantly different from the regression model composed of the covariates ($F_{(5,12)}$ = 2.223, $p$= 0.119). Active Duty status was a statistically significant predictor of Filtered Words score (β= 0.674, t=2.846, p=0.015). Standardized Regression Coefficients, t values, and $p$ values for Step 2 are reported in Table 7 below.

***Cumulative Trauma and Auditory Processing***

*Filtered Words*

Step 1 showed that variance accounted for in Filtered Words Scores ($R^2$) by Age, Sex, active duty status, and branch of service was 0.154 (adjusted $R^2$= 0.049), which was not significantly different from zero ($F_{(4,32)}$= 1.459, $p$= 0.238). In Step 2, Filtered Words Total Scores were entered into the regression model, and the change in variance accounted for ($R^2$) was 0.184: 18.4% of the variance in Filtered Words Scores was predicted by BTQ scores after controlling for covariates was not significantly different from the regression model composed of the covariates ($F_{(5,31)}$= 1.401, p= 0.251). Standardized Regression Coefficients, t values, and p values for Step 2 are reported in Table 8 below.

*Auditory Figure-Ground*

Step 1 showed that variance accounted for in Auditory Figure Ground Scores ($R^2$) by Age, Sex, active duty status, and branch of service was 0.066 (adjusted $R^2$= 0.051), which was not significantly different from zero ($F_{(4,32)}$= 0.564, $p$= 0.691). In Step 2, Auditory Figure-Ground Total Scores were entered into the regression model, and the change in variance accounted for ($R^2$) was 0.095: 9.5% of the variance in Auditory Figure-Ground Scores was predicted by BTQ scores after controlling for covariates was not significantly different from the regression model composed of the covariates ($F_{(5,31)}$= 0.648, $p$= 0.665). Standardized Regression Coefficients, t values, and p values for Step 2 are reported in Table 9 below.

## DISCUSSION

The goal of this study was to determine is Auditory Processing and Heart Rate Variability could be used concurrently with existing self-report methods in order to more accurately diagnose

PTSD. Data collection ended early due to in-person research being halted due to COVID-19, as the study could not be adapted for online presentation. Several findings were approaching statistical significance.

After controlling for the covariates, 8.3% of the variance in Auditory Figure-Ground Scores was explained by PCL-5 scores, but this was not significantly different from the amount of variance predicted by the covariates. However, there was a substantial approach towards significance, potentially explain by Branch of Service. Given that due to the location of the study, the sample population was mainly comprised of Active Duty and Veteran Sailors (U.S. Navy), this is a reasonable relationship, but in terms of general trends in the whole of the Armed Forces, is not representative.

The relationship between Heart Rate Variability- RMSSD during the Filtered Words Test, Age, and Total scores on the Filtered Words was marginally significant. Higher scores on the Filtered Words test indicate increased ability to pick single syllable words out from background noise; During the test, words are low passed through the background noise filter which as a frequency of 750 Hz, which is within the frequency range of 500-4000 Hz that is the band of perceptual advantage in humans (Porges, 2007). This can potentially be explained by the idea that when encountering a dangerous situation, rather than attending to voices, people's perception shifts to potential predator sounds (Porges, 2017), one syllable words being a close approximation to these sounds when passed through the filter. Heart Rate Variability is generally lower in individuals with PTSD and decreases under stressful conditions (Porges, 2007; Porges & Porges 2017), and did decrease while the Filtered Words Test was being conducted (and during the Auditory Figure-Ground Test as well). Heart Rate variability-RMSSD during the Filtered Words Test decreased in addition to Filtered Words Test Scores as age increased. This could be because as age increases, scores on the Filtered Words test that indicate unaltered auditory processing ability tend to decrease. This may be due to the deterioration of the Auditory system.

The Auditory Figure-Ground test yielded interesting results in that as Heart Rate Variability during the test decreased, Total scores on the test increased. Active Duty Status was a significant predictor in the regression model ($\beta = 0.701$, $t = 2.958$, $p = 0.013$), even though the overall model was marginally significant due to sample size. Initially a surprise, this increase could be related to the hypervigilant state that sometimes occurs in PTSD: When sensing if a situation is safe, the range of frequencies picked up on by the ear is expanded outside of those of the social engagement system, in an effort to detect danger or predators (Porges, 2007: Porges 2010: Porges and Porges, 2017). This could also be due to the nature of Active Duty Service: Being on active duty increases the likelihood of encountering more stressful and potentially traumatic situations, given the nature of the Profession of Arms. This constant exposure to stress may very well cause the threat sensing process in the Polyvagal System to always be "on", leading to decreased heart rate variability as there is no "stand down" or recovery period were the individual feels safe and can recover (Porges and Porges, 2017). The Social Engagement System is a more recent evolutionary development, allowing for conversation and reasoning, but when the frequency range expands to listen for predators or other danger, a less evolved defense mechanism is taking place, so that the individual can assess a situation and determine if they will fight, flee, or freeze ( Porges, 2007: Porges and Porges, 2017).

The relationship between cumulative trauma, age, and scores on the Auditory Processing tests is worth discussing as well, despite being marginally significant. As age increases, there is a greater likelihood that a person will experience one or more traumatic events, and the more trauma a person experiences, the greater the chance they have of developing PTSD (American

Psychological Association, 2013). Stress affects the functioning of the nervous system, and if chronic, can cause the body to deteriorate, which could affect auditory processing (American Psychological Association, 2018). A caveat of the SCAN-3A tests is that an individual can hear within normal range, so if stress causes deterioration of the Auditory System, it will affect outcomes on Auditory Processing tests like the Filtered Words Test and Auditory Figure-Ground test (Keith, 2009).

Having physiological measures to use in combination with interviews and survey instruments for the diagnosis of PTSD would not only serve to allow for a more diagnostic picture, but could used in the development of interventions to help reprogram the brain and body to be able to accurately sense and respond to danger ( Litz, BT, 2007; Porges, 2009; Porges, S.W. & Lewis, G.F., 2010; Porges and Porges, 2017; Volchan et al, 2017). Having a larger sample would not only serve to determine further validity of the measures used (PCL-5, BTQ, Filtered Words Test, Auditory Figure-Ground Test, and heart rate variability) as potential diagnostic measures, but serve as further support for the Polyvagal Vagal Theory.

**Limitations**

It is important to note that this study was part of a larger, multifaceted project that was a pilot test for developing potential PTSD interventions. An extensive number of health and social questionnaires were administered before physiological measures were taken, so it is entirely possible that participants were fatigued while they were being taken through the protocol (Shadish, Cook & Campbell, 2002).

One of the major limitations of this study is the small sample size (n= 38). While scheduled to meet the minimum number of participants suggested by the power analysis, COVID-19 and the accompanying safety precautions ended data collection prematurely, as the study could not be adapted for online data collection. While the within-subjects repeated measures design allows for a smaller sample when testing the reliability and validity of measures, additional participants would serve to increase the statistical power of the findings, perhaps taking the findings from marginal significance to statistical significance, given the nature of physiological data: Sensor placement may have affected data collection (Lazar, Feng, & Hochheiser, 2017).

Confounding variables in this study that were controlled for include: Sex, Branch of Service, Active Duty Status, and Age. This was due to the fact that the sample is mostly comprised of Male, veterans of the U.S. Navy with an average age of 31.86 years old: the majority of the United States Armed Forces overall is Male, with the U.S. Army being the largest service branch (Reynolds & Shendruk, 2018). The sample was also primarily comprised of veterans (78.9%). It is important to note that because the sample was composed of service members and veterans that were in a college setting, there is more flexibility than the strict, regimented nature of active military service. The sample is also primarily comprised of psychology majors, that may be more high functioning and better able to deal with stress.

It could also be argued that because of using a collegiate sample that there is a restriction of range due to age. However, the average of age of participants was 31.86 years old, well outside the age range of traditionally aged college students (18-22 years old). This too could be tied to Active Duty Status.

While the eMotion Faros 180 Heart Rate monitoring system improved the flow of the experimental protocol due to the ability to not be tethered to a single spot, it was impossible to ascertain if the monitors were actually recording data until after a participant had completed the protocol. Further training with the eMotion Faros 180 monitor to ensure it is collecting data or changing to a tethered Heart Rate Monitor would help ensure the important physiological data is not being lost.

Ultra-Short-term recordings of less than 5 minutes were used to determine a baseline for each participant's Heart Rate variability. Because there are not established ranges for high and low Heart Rate Variability, having a longer baseline measurement would make departures from a participant's average heart rate variability more visible and could therefore be attributed to the experimental procedure.

The nature of the Auditory Processing measures, the Filtered Words Test and the Auditory figure-Ground Test, may be stressful to participants, some more than others.  As such, this may affect Heart Rate variability and make any changes in it exaggerated when compared to baseline measures.

It is possible that the PCL-5 sum score was not the best way to measure PTSD. Recent research suggests that Hypervigilance and Hyperreactivity, featured in Cluster E of PTSD symptoms (Items 15-20 of the PCL-5), may be a better indicator of PTSD than a simple sum score (Kimble, Fleming, & Bennion, 2013). This appears logical as it would potentially explain why participants may have performed better on the Auditory Figure Ground test when they had a higher PCL-5 sum score. Investigating all the symptom clusters of PTSD and how they may be related to Auditory Processing could prove interesting and insightful.

**Future Directions**

One of the next steps for this study would be examining these measures in a population of military veterans and active duty personnel that are not enrolled in college but are experiencing PTSD and stress. Because the majority of the participant were psychology students, it's possible they were higher functioning and better able to deal with stress. It is also possible that a collegiate sample may have had less exposure to trauma. Additionally, by expanding to a non-collegiate sample, there is a greater likelihood conflicts other than those in Iraq and Afghanistan would be reflected, such as the Vietnam War. By expanding the sample outside of a college setting, this could increase the generalizability of these findings.

A more accurate pre-study baseline could be gained by having Heart Rate Variability data collected for 24 hours before the start of the experimental procedure. This would be helpful so as to eliminate artifacts and make changes in Heart Rate Variability more visible, as there are not yet established ranges for High and Low heart rate variability, and changes in it are based solely on an individual's deviation from their normal Heart Rate variability.

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Tables

Table 1

Correlations Between Predictors, Criterion, and Demographics

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1.Deployment | | .353* | .225 | -.163 | -.212 | -.115 | .472* | .494* | .101 | .037 |
| 2.PCL-5 Total | .353* | | .253 | -.200 | -.204 | .537* | .032 | -.038 | .013 | 0.044 |
| 3.Active Duty | .225 | .253 | | -.432* | -.409* | -.300 | .184 | -.237 | -.106 | .204 |
| 4.FW HRV | -.163 | -.200 | -.432* | | .964* | .785** | .011 | -.237 | .057 | -.144 |
| 5.AFG HRV | -.212 | -.204 | -.409* | .964** | | .735** | -.078 | -.332 | -.007 | -.098 |
| 6.Baseline | -.115 | .537* | -.300 | .735** | .750** | | .034 | -.094 | .785* | .022 |
| 7.Branch | .472* | .032 | .184 | .011 | -.078 | .034 | | .230 | .286 | .042 |
| 8.Paygrade | .494 | -.038 | -.237 | -.237 | -.032 | -.094 | .230 | | .130 | .113 |
| 9.FW Total | .101 | .013 | -.106 | .057 | -.007 | .785** | .286 | .130 | | .557** |
| 10.AFG Total | .037 | .044 | .204 | -.144 | -.098 | .022 | .042 | .113 | .557** | |

*Note*: Correlations checking for collinearity between demographics, predictors, and criterion variables. * denotes $p<0.05$, ** denotes $p< 0.001$. Key: Active duty - Active Duty Status, FW- Filtered Words, AFG- Auditory Figure-Ground, HRV- Heart Rate Variability, Baseline- Pre-Auditory Baseline HRV, Branch- Service Branch.

Table 2 Regression: PCL-5 and Filtered Words

| | β | t | *p* |
|---|---|---|---|
| Sex | 0.048 | 0.267 | 0.791 |
| Branch of Service | 0.021 | 0.115 | 0.909 |
| Active Duty Status | 0.237 | 1.256 | 0.218 |
| Age | -0.165 | -0.859 | 0.397 |
| PCL-5 Sum Score | 0.049 | 0.258 | 0.798 |

*Note*. Standardized Regression Coefficients, t values and *p* values for Step 2 of the Hierarchical Linear Regression between PCL-5 sum scores and Filtered Words Total Score.

Table 3 Regression: PCL-5 and Auditory Figure Ground

| | β | t | *p* |
|---|---|---|---|
| Sex | 0.129 | 0.757 | 0.455 |
| Branch of Service | 0.349 | 2.063 | 0.048 |
| Active Duty Status | -0.140 | -0.788 | 0.436 |
| Age | -0.217 | -1.196 | 0.241 |
| PCL-5 Sum Score | 0.135 | 0.757 | 0.458 |

Table 3. Standardized Regression Coefficients, t values and *p* values for Step 2 of the Hierarchical Linear Regression between PCL-5 sum scores and Auditory Figure-Ground Total Score.

Table 4 Regression: RMSSD HRV and Filtered Words

| | β | t | *p* |
|---|---|---|---|
| Sex | -0.048 | -0.182 | 0.859 |
| Branch of Service | 0.284 | 1.069 | 0.306 |
| Active Duty Status | -0.310 | -1.109 | 0.289 |
| Age | 0.415 | 1.470 | 0.167 |
| Filtered Words RMSSD | 0.107 | 0.387 | 0.705 |

Table 4. Standardized Regression Coefficients, t values and *p* values for Step 2 of the Hierarchical Linear Regression between Heart Rate Variability-RMSSD during the Filtered Words Test and Filtered Words Test Total Score.

Table 5 Regression: HF HRV and Filtered Words

| | β | t | *p* |
|---|---|---|---|
| Sex | 0.088 | 0.321 | 0.753 |
| Branch of Service | 0.226 | 0.882 | 0.395 |
| Active Duty Status | -0.213 | -0.733 | 0.478 |
| Age | 0.482 | 1.787 | 0.099 |
| Filtered Words HF | 0.053 | 0.934 | 0.369 |

Table 5. Standardized Regression Coefficients, t values and *p* values for Step 2 of the Hierarchical Linear Regression between Heart Rate Variability-HF during the Filtered Words Test and Filtered Words Test Total Score.

Table 6 Regression: RMSSD HRV and Auditory Figure Ground

| | β | t | p |
|---|---|---|---|
| Sex | -0.143 | -0.583 | 0.571 |
| Branch of Service | -0.327 | -1.336 | 0.206 |
| Active Duty Status | 0.585 | 2.303 | 0.040 |
| Age | -0.370 | -1.486 | 0.163 |
| Figure-Ground RMSSD | 0.116 | 0.460 | 0.654 |

Table 6. Standardized Regression Coefficients, t values and *p* values for Step 2 of the Hierarchical Linear Regression between Heart Rate Variability-RMSSD during the Auditory Figure- Ground Test and Auditory Figure-Ground Test Total Score.

Table 7 Regression: HF HRV and Auditory Figure Ground

| | β | t | *p* |
|---|---|---|---|
| Sex | -0.002 | -0.008 | 0.994 |
| Branch of Service | -0.378 | -1.722 | 0.111 |
| Active Duty Status | 0.674 | 2.846 | 0.015 |
| Age | -0.392 | -1.734 | 0.109 |
| Figure-Ground RMSSD | 0.406 | 1.682 | 0.118 |

Table 7. Standardized Regression Coefficients, t values and *p* values for Step 2 of the Hierarchical Linear Regression between Heart Rate Variability- HF during the Auditory Figure-Ground Test and Auditory Figure-Ground Test Total Score.

Table 8 Regression: Cumulative Trauma and Filtered Words

| | β | t | *p* |
|---|---|---|---|
| Sex | 0.118 | 0.708 | 0.485 |
| Branch of Service | 0.376 | 2.208 | 0.035 |
| Active Duty Status | -0.136 | -0.777 | 0.443 |
| Age | -0.114 | -0.622 | 0.538 |
| Filtered Words Total | -0.187 | -1.068 | 0.294 |

Table 8. Standardized Regression Coefficients, t values and *p* values for Step 2 of the Hierarchical Linear Regression between BTQ Total Scores and Filtered Words Total Scores.

Table 9 Regression: Cumulative Trauma and Auditory Figure Ground

| | β | t | *p* |
|---|---|---|---|
| Sex | 0.049 | 0.277 | 0.784 |
| Branch of Service | 0.051 | 0.0286 | 0.777 |
| Active Duty Status | 0.227 | 1.234 | 0.227 |
| Age | -0.088 | -0.454 | 0.653 |
| Figure-Ground Total | -0.183 | -0.994 | 0.328 |

Table 9. Standardized Regression Coefficients, t values and *p* values for Step 2 of the Hierarchical Linear Regression between BTQ Total Scores and Auditory Figure-Ground Total Scores.

Figures

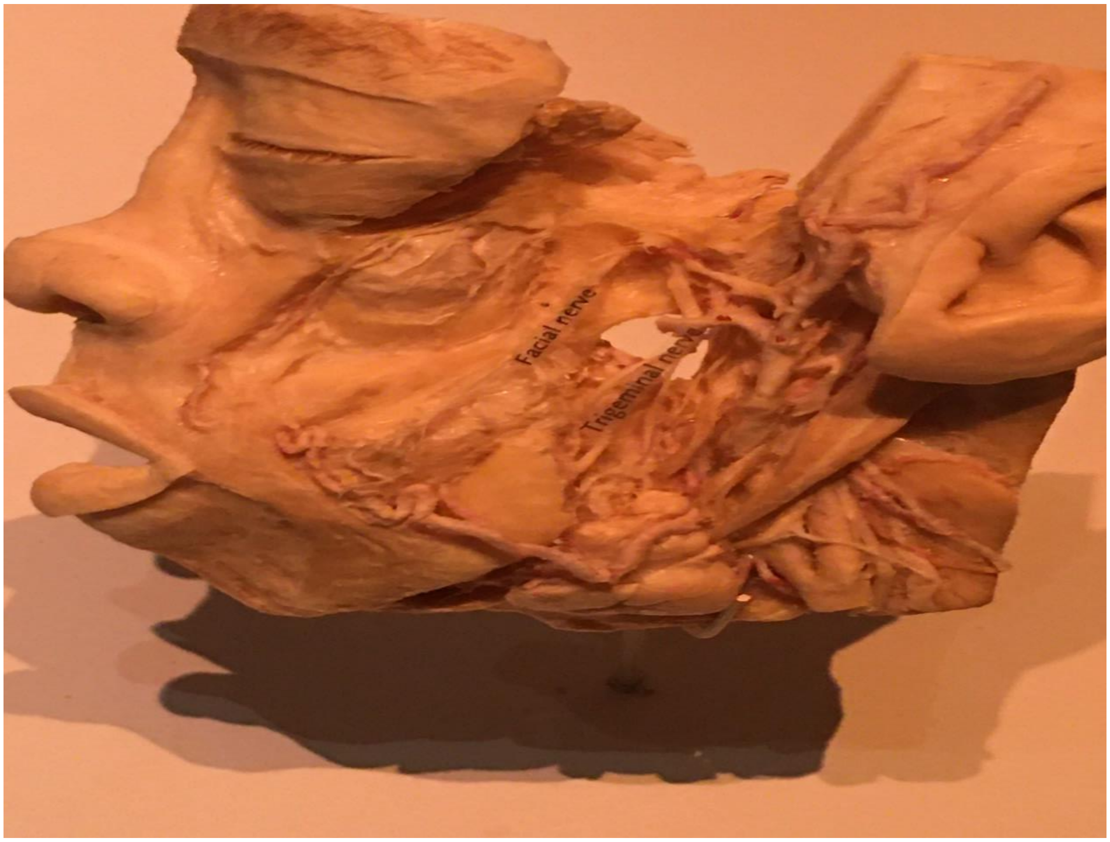


Figure 1: Anatomy of the Face showing the Facial and Trigeminal Cranial Nerves. From the “Think” section of the Bodies at Bally’s exhibit, Las Vegas, NV.


Figure 2. Auditory Ossicles, malleus (hammer), the incus (anvil), and the stapes (stirrup).

From the “Think” section of the Bodies at Bally’s exhibit, Las Vegas, NV

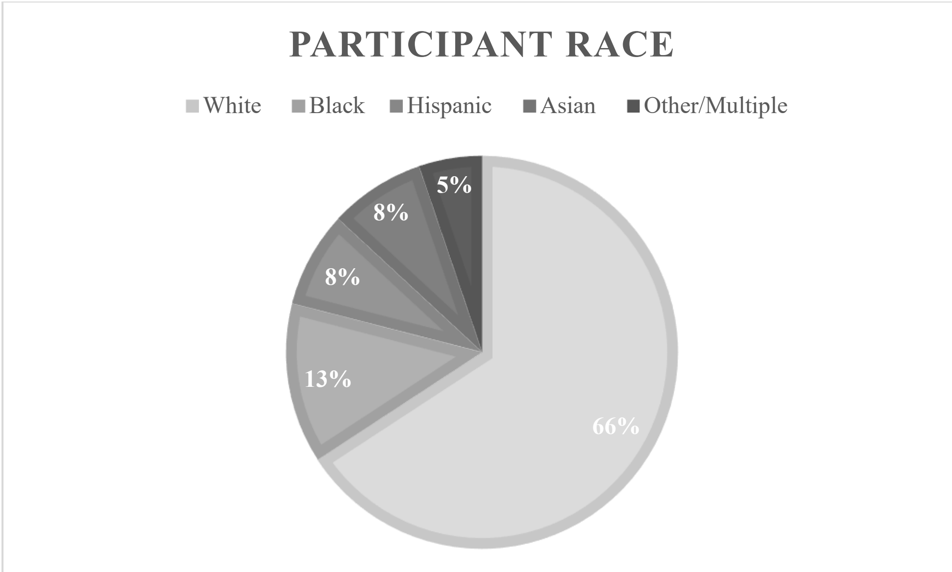


Figure 3. Breakdown of the race of participants in the study

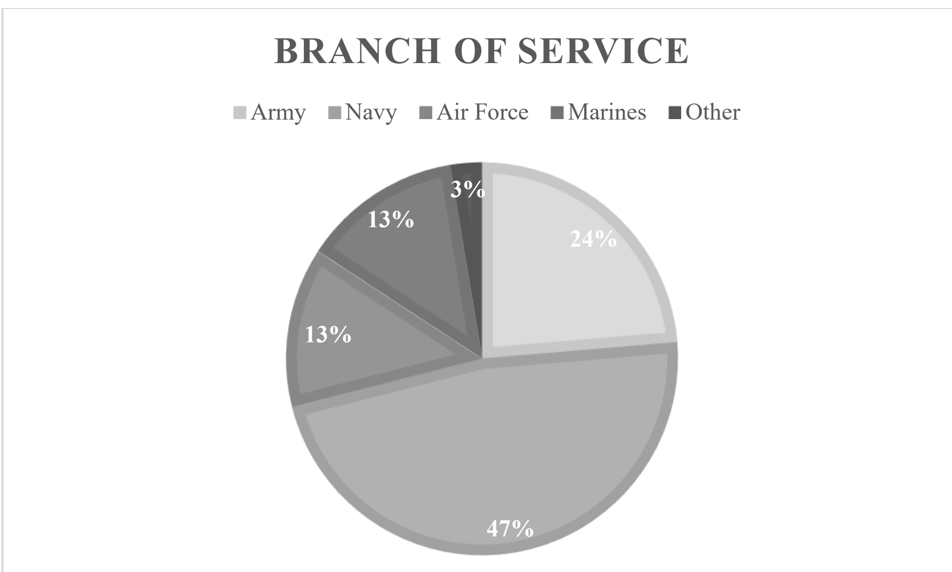


Figure 4. Branch of Service of Participants

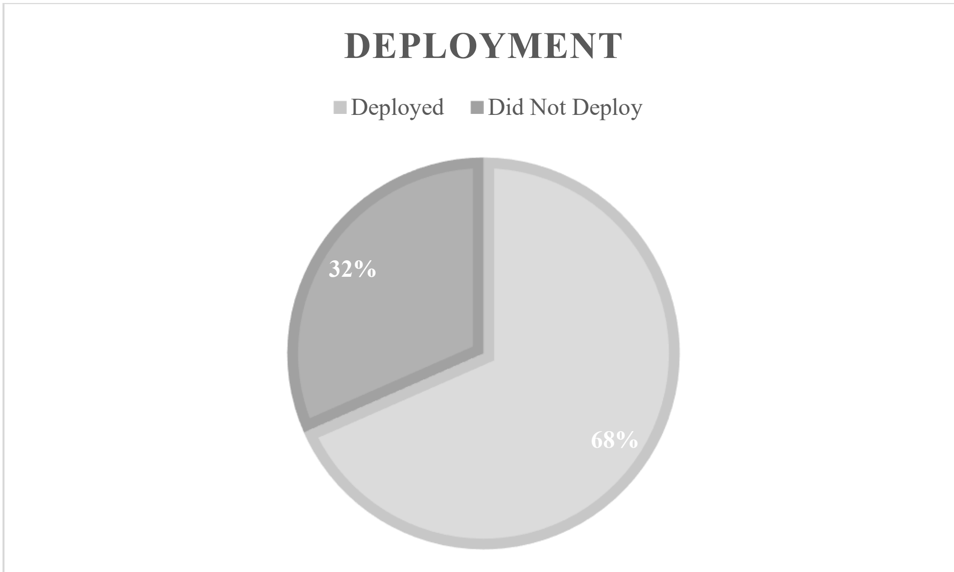


Figure 5. Percentage of participants that had deployed at least once

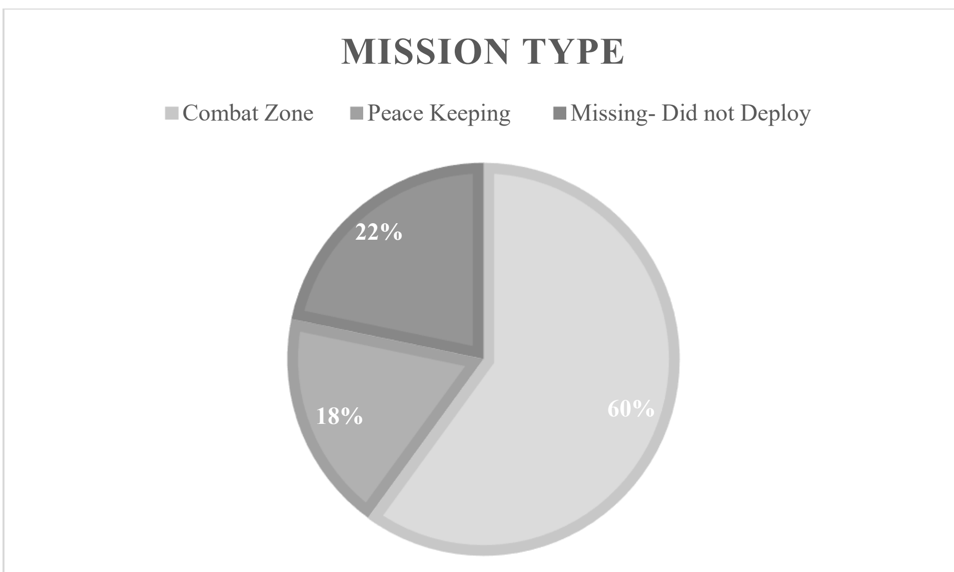


Figure 6. Type of mission to which participants deployed

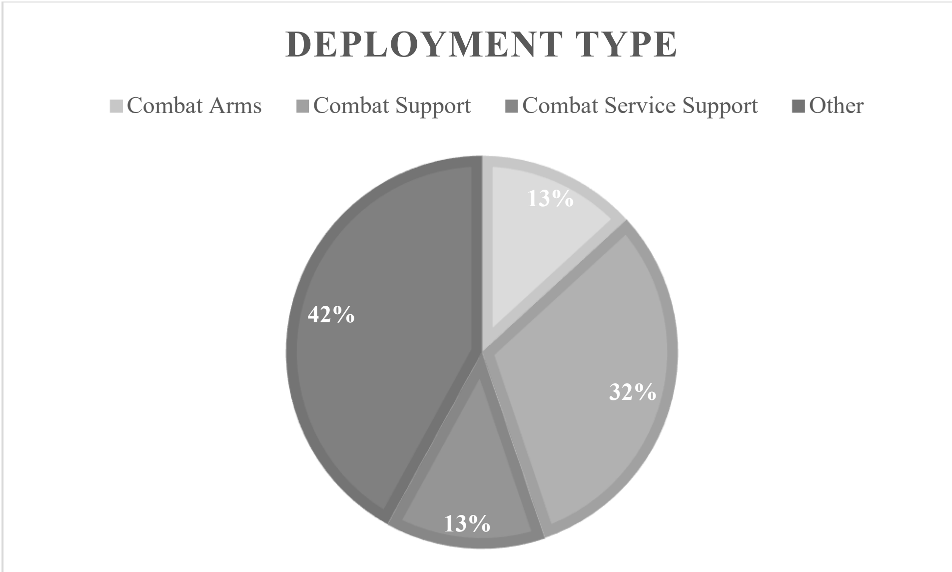


Figure 7. Type of duty while deployed