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Olfaction, Memory, and Presence in Warfighters: Do the Scents of War Matter?

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ODORANTS, MEMORY, AND PRESENCE IN WARFIGHTERS: DO THE SCENTS OF WAR MATTER?

by

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ABSTRACT

Background: Exposure therapy (EXP) is a first-line intervention for combat-related PTSD. EXP works by repeatedly exposing the patient to the feared stimuli, situation, or physical sensations in the absence of actual danger until the stimuli no longer evoke maladaptive responses. Over the past decade, multiple technologies have been introduced to augment the EXP process by presenting multi-sensory cues (e.g., sights, smells, sounds) to increase patients' sense of presence. Exploratory research has only broadly examined the effect of odorants on the patient's sense of presence during simulated exposure tasks. This study hypothesized that those with autobiographical memories similar to the virtual environment (VE) and those who received odorants would report experiencing more presence than experimental controls. **Methods:** 61 veterans and civilian subjects were randomized and asked to participate in a virtual environment simulating a routine OIF/OEF/OND convoy. The effects of odorants and autobiographical memory on presence were assessed via electrodermal activity, respiration, heart rate variability, and self-report measures. **Results:** Odorants did not significantly influence presence. A relationship between military experience and presence, HRV, and realism was observed. **Conclusion:** Odorants did not have a statistically significant effect on presence while engaged in a simulated exposure task, which was inconsistent with previous research. The rationale for these findings and recommendations for future research are made.

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ABBREVIATIONS

INTRODUCTION

Posttraumatic Stress Disorder

Posttraumatic Stress Disorder (PTSD) has been called one of the "signature wounds of the Iraq war" (Tanielian & Jaycox, 2008), with prevalence currently estimated at over 13% of operational infantry forces and 5% of total deployed forces (Kok, Herrell, Thomas, & Hoge, 2012). The high prevalence within operational units represents significant demand for mental health service providers. However, providing care for service members may be challenging due to stigma (Hoge et al., 2004; Kim, Thomas, Wilk, Castro, & Hoge, 2010), limited appointment availability (Sareen et al., 2007), and negative perceptions of care (Kim, Britt, Klocko, Riviere, & Adler, 2011; Sudom, Zamorski, & Garber, 2012) which appear to result in an overall treatment reach that is limited (Hoge et al., 2014).

Olesen, Gustavsson, Svensson, Wittchen, and Jönsson (2012) estimated the approximate annual cost of PTSD to be $10 trillion dollars in Europe alone. The Congressional Budget Office reported the direct cost of treating PTSD in American warfighters (a minuscule subset of the overall US population) between 2004-2009 was approximately 1.4 trillion dollars (Bass & Golding, 2012). Lépine (2002) has suggested additional, indirect expenses (such as reduced productivity and absenteeism) increase costs associated with mental health disorders. In addition, PTSD is also often compounded by other medical needs (Frayne et al., 2011) as well as depression (Campbell et al., 2007), which further increase the financial burden tied to mental health.

Some of the symptoms associated with PTSD are part of the normal reaction to trauma. These include difficulty concentrating or sleeping, as well as intrusive and trauma-related thoughts or images. Many people who experience a traumatic event naturally recover as demonstrated by a

decline in distress over time. In a civilian sample, nearly 90% of adults reported experiencing a traumatic event, but only a small subset developed PTSD (Kilpatrick et al., 2013). A DSM-5 diagnosis of PTSD requires symptoms to be present for at least 30 days and requires clinically distressing symptoms be present across five criteria, including a) exposure to actual or threatened death, serious injury, or sexual violence, b) intrusive symptoms, including thoughts or memories, c) avoidance of reminders of the event, d) cognition and mood symptoms, such as difficulty remembering important aspects of the event, or persistent negative expectations, and e) arousal or reactivity symptoms, which include irritability and hypervigilance (American Psychiatric Association, 2013).

While PTSD is no longer classified as an anxiety disorder, behavioral avoidance in PTSD is similar to that seen in anxiety disorders such as panic or specific phobias. Avoidance of trauma-related reminders prevents distressing memories from arising, preventing anxious and fearful thoughts and negative feelings associated with the traumatic memory. Unfortunately, avoiding thoughts and feelings associated with the event prevents those suffering from PTSD from learning new and more adaptive response patterns (Foa, Huppert, & Cahill, 2006; Foa & Kozak, 1986).

Ehlers and Clark (2000) have described avoidance as a maladaptive control strategy which short-circuits disconfirmation of negative appraisals. This failure to allow disconfirmation results in the maintenance of the perceived threat. Behavioral avoidance has been seen in various populations with PTSD, including combat veterans (Pietrzak, Harpaz-Rotem, & Southwick, 2011), victims of sexual assault and abuse (Fleurkens, Rinck, & van Minnen, 2014), and motor vehicle accident victims (Delahanty et al., 1997). By encouraging patients to face anxiety-provoking

situations, thereby preventing the avoidant behavior, incompatible and erroneous information can be corrected with more appropriate behavioral responses that enable better daily functioning.

Exposure Therapy

Exposure therapy (EXP) is an empirically supported treatment for anxiety disorders (Opriş et al., 2012; Parsons & Rizzo, 2008) and PTSD (Powers & Emmelkamp, 2008; Powers, Halpern, Ferenschak, Gillihan, & Foa, 2010). EXP is an intervention grounded in the principles of classical conditioning as observed by Pavlov (1902) and Watson and Rayner (1920) and is similar to fear extinction models used in animals (Myers & Davis, 2007). An example of classical conditioning in combat-related PTSD might include avoidance of crowds after experiencing the detonation of an improvised explosive device (IED) in a crowded market, which threatened the life of the patient. The goal of EXP is to extinguish behaviors that are (or have become) maladaptive, by exposing the patient to the anxiety or fear-producing stimulus (or a facsimile of that stimulus) without exposing the patient to actual danger. Stimuli constellations are often perceived as harmless to outside observers but serve as "triggers" or, put more formally, fear-structures that are perceived as highly dangerous by warfighters with PTSD. In the IED example used earlier, this constellation might include the scent of smoke, diesel, and body odor, accompanied by tactile vibrations and loud explosions. By activating these fear-structures in the absence of danger or negative outcomes, corrective information acts upon and modifies the pathological component of the fear structure until the patient no longer experiences the distressing symptoms, thoughts, or emotions. This process allows new information and more adaptive expectations to be learned. EXP can be conducted both imaginally (where the patient imagines the feared stimulus or situation), and *in vivo* (in life, where people are physically engaged with a facsimile of, or the actual feared stimulus or situation).

Including multiple sensory modalities during EXP (either imaginal or in vivo) that are associated with the stimulus or situation appear to enhance learning (Rescorla, 2006). Recently, researchers utilizing EXP for PTSD have increased utilization of multimodal sensory systems during EXP to create high fidelity virtual environments (VEs) for use in EXP (Gerardi, Cukor, Difede, Rizzo, & Rothbaum, 2010; McLay et al., 2011; Rizzo et al., 2009; Rizzo, Reger, Gahm, Difede, & Rothbaum, 2009). These multi-sensory systems include 3D visuals, sounds, tactile feedback (platforms that vibrate during explosions, for instance), and odorants (such as the scent of diesel fuel). The inclusion of multiple stimuli serves multiple purposes, which includes reducing mental strain required to imagine or visualize the event, and reducing patient avoidance. Both behavioral and cognitive avoidance are common in patients with PTSD and counteract the theoretical mechanisms of EXP by limiting exposure to conditioned stimuli (CS) in the absence of unconditioned stimuli (US). The direct delivery of multisensory and trauma-related cues helps to circumvent patient avoidance. The inclusion of multiple trauma-related stimuli may also increase a patient's degree of presence during EXP.

Presence

Presence was first formally defined by Sheridan (1992) as "the sense of physically being present with visual, auditory, or force displays generated by a computer." He proposed that presence is a subjective state produced when subjects are provided high-fidelity sensory information, the ability to change the environment, and willingness to engage with the VE. The term presence is not unified in its use, and several competing definitions and conceptualizations exist, which are examined in Lombard and Ditton (1997) and more recently, Procci (2015). These conceptualizations include presence as realism, or the capability of a system to produce high fidelity reproductions of real-world objects (Hatada, Sakata, & Kusaka, 1980; Neuman,

1990). The conceptualization of realism defined presence as a system's ability to create virtual objects that have high degrees of fidelity to their real-world counterparts. Presence has also been thought of as transporting an audience to another time/place through various mechanisms (e.g., narratives, storytelling, or television) where users feel as though they are physically somewhere they are not (Biocca & Delaney, 1995; Gerrig, 1993; Minsky, 1980; Reeves, 1991). Presence as a social actor (Lombard, 1995) is perhaps one of the conceptualizations public consumers are most familiar with, though they may not be aware of it. Many smartphones currently implement virtual assistants (e.g., Apple's Siri, Microsoft's Cortana, and Amazon's Alexa) capable of "interacting" with users. According to the social actor conceptualization, users who interact with these programs, as they would with actual people, experience presence. Presence has also been conceptualized as (and sometimes used interchangeably with the terms) perceptual or psychological immersion (Lombard & Ditton, 1997). Contemporary definitions of presence state that presence is caused by (as quoted in Procci, 2015, p. 247):

- *…high levels of overall immersion, a combination of:*
- *Immersive cues provided by the video game (e.g., high-fidelity, increased field of view, HMD, naturalistic inputs, etc.)*
- *Lots of immersive cues make it easier to confirm and needs more distractions to take away*
- *Personal involvement and motivation to be present*
- *Creative imagination and willingness to suspend disbelief*

As the definitions of presence and immersion solidified in the early 2000's, the accurate measurement of presence began to be explored. IJsselsteijn, De Kort, Poels, Jurgelionis, and Bellotti (2007) reviewed methodologies used to assess presence, including subjective and objective methods. Subjective measurements included self-report rating scales and psychophysical ratings. Several self-report measures are currently in use for measuring presence, including the Presence Questionnaire (Witmer & Singer, 1998) and the iGroup Presence Questionnaire (Schubert, Friedmann, & Regenbrecht, 2001). For psychophysical ratings, users are asked to determine if a location in a photo is real or that of a VE (Schloerb, 1995); however, it is important to note that the psychophysical rating method has been criticized in its ability to assess presence rather than simply an ability to judge images as rendered or real (IJsselsteijn et al., 2007). One important point offered by IJsselsteijn and colleagues is that subjective measures often fail if participants or subjects fail to understand the definition of presence and that objective measures that correlate to subjective measures are useful when assessing presence. The authors specifically noted the use of physiological measures to quantify presence, such as heart rate (HR) and galvanic skin response (GSR; now referred to as electrodermal response activity or EDA). The rationale for these two specific physiological methods is EDA's association with arousal, and HR's association to hedonic value, in which pleasant stimuli decrease heart rate and aversive stimuli increase heart rate. Unfortunately, the value of EDA is unknown, as mixed results have been reported in the literature (Drachen, Nacke, Yannakakis, & Pedersen, 2010; Wiederhold, Davis, & Wiederhold, 1998).

It has been argued that presence is of critical importance when using VEs in psychotherapy (Sanchez-Vives & Slater, 2005) but the relationship between presence and VEs utilized in exposure therapy is currently poorly understood. Which elements are critical to evoke

a presence response, and what fidelity is required? Display parameters, visual realism, sound, haptics, body representation, and engagement have been the most explored areas pertinent to presence (see Sanchez-Vives & Slater, 2005 for a review), while olfaction's effect on presence has generally received less attention (Aiken & Berry, 2015).

Olfaction

The ability to smell is found in almost all animal species (Wilson & Stevenson, 2006). Olfaction provides information that is particularly important in many daily functions, such as the detection and identification of food. Scents or odorants may be environmental (soil, minerals) or biological (pheromones). Simply stated, the primary function of the olfactory system is to permit an organism to identify odorants. This is accomplished through receptor cells and membranes that respond to chemical molecule compositions. For some odorants, the amount of chemical required for detection can be minuscule but can provide critical information relevant to the organism's survival. While seemingly simple, the process of olfaction is mechanically complex, and the perception of odorants depends on not only on the detection of chemical compounds but also one's expectations and contextual information.

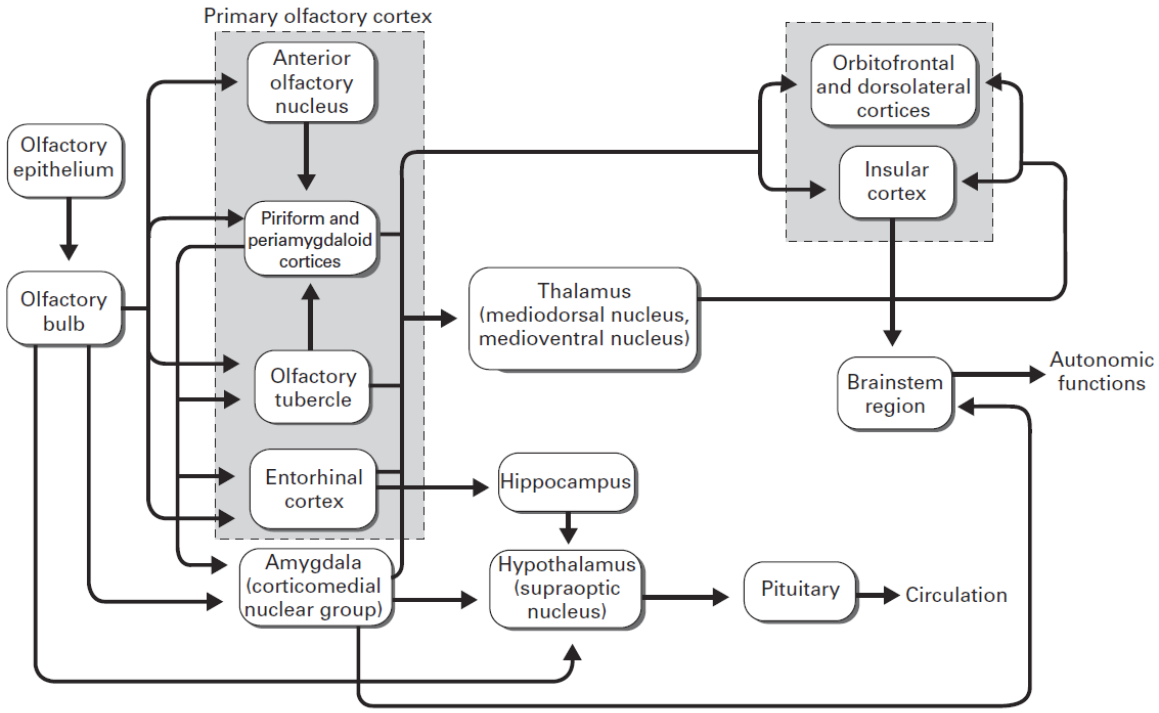


Figure 1: Schematic Diagram of the Olfactory System

Note: The connection between olfactory bulb and the hypothalamus is not established in humans. Used with permission by Cambridge University Press.

Olfaction begins within the nasal cavity at the olfactory bulb, where 5-15% of inhaled air is diverted towards receptors (Keyhani, Scherer, & Mozell, 1995). There are an estimated six million olfactory receptor cells within each nostril (Moran, Rowley III, Jafek, & Lovell, 1982), which are situated in the olfactory epithelium (Figure 1). These cells are the primary receptors of the olfactory system and serve sensory information to the olfactory bulb, which filters and modifies sensory information.

Information is then sent from the olfactory bulb to the primary olfactory cortex (POC) and the amygdala. The POC is comprised of the 1) anterior olfactory nucleus, 2) piriform and

peri amygdaloid cortices, 3) olfactory tubercle, and 4) entorhinal cortex. The anterior olfactory nucleus appears to regulate information flow between regions dealing with olfactory information (Brunjes, Illig, & Meyer, 2005). The piriform cortex has been implicated in odor recognition (Dade, Zatorre, & Jones-Gotman, 2002; Plailly et al., 2005), representation of odor properties (Gottfried, Winston, & Dolan, 2006), odor valence (Gottfried, Deichmann, Winston, & Dolan, 2002) and odor attention (Zelano et al., 2005), while the peri amygdaloid and entorhinal cortices assist in the processing of olfactory information (Biella & de Curtis, 2000; Majak & Pitkanen, 2003). Information processed by the POC is then passed to the thalamus and hippocampus, while other information is passed directly from the olfactory bulb to the amygdala.

The olfactory system has the most direct connection to the hippocampus (synaptically) compared to all other sensory systems. It is largely accepted that the hippocampus is involved in the formation of memories about experienced events (Burgess, Maguire, & O'Keefe, 2002; Eichenbaum, 1993). It has also been suggested that the hippocampus and amygdala act in unison when emotion and memory are connected. Phelps (2004) describe the amygdala's function in modulating the encoding and storage of hippocampal-dependent memories. This is in addition to the hippocampus' influence on amygdala responses when emotional stimuli, such as those encountered during traumatic events, are presented.

The power of odorants is often anecdotally discussed when discussing memories. It has been suggested that scents are strong cues for memories past, a connection first described in Swann's Way (Proust, 1925). Research has demonstrated that odorants result in memory recall with greater emotional potency than verbal or visual stimuli (Chu & Downes, 2000; Chu & Downes, 2002; Herz, 1998; Herz & Cupchik, 1995; Herz & Engen, 1996). The connection

between odorants and memory has, more recently, been leveraged in exposure therapy with combat veterans. For warfighters who served in OIF/OEF/OND, odorants such as cordite, burning rubber, garbage, and diesel fuel have been used (Rizzo et al., 2010; Rizzo et al., 2008). The effect of war-related odorants on veterans is not new; Kline and Rausch (1985) described how war-related odorants served as precipitants of flashbacks in Vietnam veterans. More recently, Vermetten and Bremner (2003) presented a vivid example of the emotional impact odorants can have when paired with traumatic events:

> *I found my wife out on the back deck watching a fire that was about 300 feet away. This is when I noticed the smell of burning rubber, together with a faint smell of fuel oil or diesel oil. My wife stated she was worried about me because I was standing on the deck as if I was daydreaming for some minutes without responding to her. The smell brought to my mind the image of this burning Amtrak, again so vivid. The Amtrak was hit. The front door/ramp was open; both crew hatches were open and pouring out smoke and flame. Thick, black, acid smoke was boiling out of the troop compartment. There was an overpowering smell of burning rubber. I remember that smell and what it looked like that day vividly. There was nothing I could have done to save the people in the Amtrak. Fifteen Marines and three crew members died there that day. I felt the same hopelessness as I felt that day. I felt bad in my stomach, got a headache, and had a feeling of futility or finality when I thought about that incident* (page 203, paragraph 3).

While the link between odorants and memory appears to be generally accepted, little research has focused on the effect of odorants on veterans' sense of presence during EXP. While

odorants have been shown to increase presence in more general VE's (Dinh, Walker, Hodges, Song, & Kobayashi, 1999), the study did not examine the link within a treatment specific context.

Memory

Autobiographical memory has been defined as the mental representation of events from one's past and includes semantic information about one's self (Conway, 2005). Those with PTSD are often able to recall vivid details about their respective traumatic events. When discussed, it appears that presence is often assessed with little regard to a users' autobiographical experience or memory within the virtual environment. Instead, the extant literature appears to examine a user's ability to recall aspects of a virtual environment after an experiment which manipulated odorants has concluded. For example, Dinh, Walker, Hodges, Song, and Kobayashi (1999) examined sensory factors that increased user's recall of a VE. Similarly, researchers have compared perceived presence between real, HMD, and audio-only conditions, but failed to address previous experience (Mania & Chalmers, 2001). Limited research has only anecdotally noted significant differences in combat-related behaviors which trended with actual experience, which may suggest memory or experience is drawn upon by users when engaging with a VE (Kaber et al., 2013). Unfortunately, presence was not a variable of interest within that study. This dearth of information regarding the effect of memory or experience upon presence is important for clinical interventions based on exposing a patient to a VE rooted in autobiographical memory.

Understanding the relationship between memory, presence, and olfaction may result in improved intervention planning and treatment outcome. If personal experience influences presence, special attention may be required to ensure the deployment of VE's congruent with

patient memories. Similarly, if odorants enhance the sense of presence in veterans and service members in an environment during simulated exposure tasks, it seems logical that exposure therapy may be more effective when olfactory cues are added. This study hypothesized the following:

1) Participants who received odorants during a simulated task would experience greater levels of presence than those who did not receive odorants. This finding would replicate the findings of Munyan, Neer, Beidel, and Jentsch (2016).

2) Participants who received odorants during simulated tasks would have differing levels of physiological activity than those who did not receive odorants. It was expected that increased presence might place an increased demand upon the autonomic nervous system, which may then be observed via increased anxiety and/or arousal.

3) Veterans would experience greater levels of presence than noncombat civilian controls, regardless of odorant condition. We expected that combat experience or autobiographical memory similar to the VE would cause participants to feel greater presence than those without similar experiences.

4) Veterans would experience greater EDA levels and HRV than noncombat civilian controls, regardless of odorant condition. We expected veterans would engage with the VE to a higher degree than their noncombat peers given their experience in potentially dangerous

situations. We believed their experience in real-world combat zones might have driven increased ANS activation.

METHODS

This study asked participants to navigate a VE identical to those currently being used in the treatment of combat-related PTSD (Rizzo, Hartholt, Grimani, Leeds, & Liewer, 2014). We immersed the user in a mildly anxiety-producing situation (a military convoy along a potentially dangerous route) in order to simulate the arousal seen in patients during exposure therapy, albeit at a non-clinical level. After the informed consent process, participants completed questionnaires to acquire demographic information as well as data related to their immersive tendencies and state anxiety. They were then fitted with electrodes connected to the physiological recorder and assisted into the virtual reality equipment by experiment staff. The initial virtual area participants experienced allowed them to familiarize themselves with the head-mounted display (HMD) prior to the experiment beginning. After a five-minute baseline period, pre-recorded instructions were delivered to the participant via headphones. Once they indicated that they were ready to begin, the exposure task began. The VE exposure task lasted approximately 10 minutes.

Veteran participants and civilian noncombat controls were randomized to either an odorant condition or a control (no odorant) condition (See Figure 2).

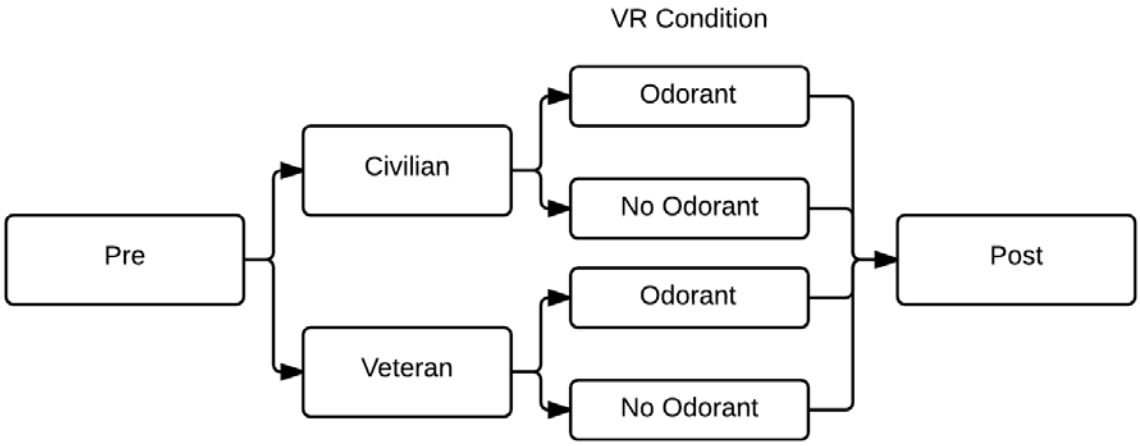


Figure 2: Experiment Design

Participants

Online and community announcements were made in the Orlando, Florida area. Recruiting announcements included flyers and announcements to online veterans, military, and community groups as approved by the IRB. A total of 232 potential participants completed the online prescreen assessment. Reasons for disqualification included the following: 18 had PCL-5 scores above the utilized cutoff of 33, 17 were ineligible due to tobacco use, 5 reported current illness during the experiment window, 4 reported some degree of anosmia, and 2 had a history of seizures and/or epilepsy. Of the remaining potential participants, 125 did not return requests made by the experimenter to schedule participation times. Participant flow can be seen in Figure 3.

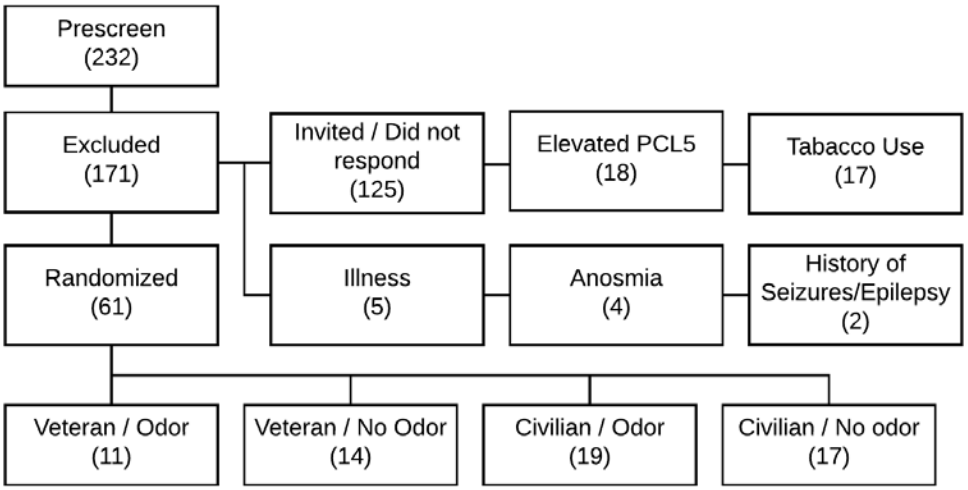


Figure 3: Participant Flowchart

The final sample consisted of 61 adult males between the ages of 17 and 61 (M = 25.2, SD = 9.68.) The sample was predominately white (61%) and included participants of Latino (13%), Asian (11%), Black (7%), and other (8%) races. Demographic information can be viewed in Table 1.

Table 1: Demographic Information

Race	***n***	**Military Branch (*if applicable*)**	***n***
White	37	Army	15
Latino	8	Air Force	4
Asian	7	Marines	3
African American	4	Navy	3
Other	3		
American Indian or Alaska Native	1		
Native Hawaiian or Pacific Islander	1		
Education	***n***	**Marital Status**	***n***
High School Diploma / GED	37	Single/Never Married	43
Associates Degree	15	Married	14
Bachelor's Degree	4	Divorced	4
Graduate Degree	5		

Both the military and civilian control groups were queried about previous experiences that may have been similar to the VE to ensure distinctiveness between-groups and verify the degree of fit between the VE and the participants' background. For example, those with military backgrounds were asked to report the number of times they had deployed, their total time spent deployed, where they deployed, and other details pertaining to their service as they related to the VE. All veteran or military participants reported taking part in convoy operations during deployments to the Middle East in support of operations OIF/OEF/OND. Within this sample, 52% reported deployments to Iraq (n = 13), Afghanistan (n = 7, 28%), and other countries in the region (n = 5, 20%). Discrete periods of overseas deployment ranged from one to seven (M = 2.04, SD = 1.45) with total time spent deployed ranging from 6 to 48-months (M = 12.16, SD =

23.46). Within the military groups, 72% reported the primary vehicle utilized during convoy operations was a HUMVEE or a HUMVEE variant (n = 18).

Similar questions were asked of the civilian control sample to ensure no analogous experiences might confound data analyses. Specifically, civilian controls were asked if they had been employed in any position that entailed driving or commuting long distances. No control participants endorsed a history of such employment. Control participants were also asked if they had ever served in a capacity that may have exposed them to traumatic events, such as an EMT, first responder, firefighter, or police officer. Again, no controls endorsed employment or personal experience within these fields of work/training.

Measures

Clinician-Administered PTSD Scale for DSM-5 (CAPS-5)

The Clinician-Administered PTSD Scale (CAPS) for DSM-5 (Weathers et al., 2013) was used to assess PTSD symptomology in participants. The CAPS interview is a 30-item semistructured interview used to assess both the frequency and intensity of PTSD symptoms and is the "gold standard" for assessing PTSD symptoms. The CAPS was administered to participants scoring a 33 or greater on the PCL-5 (see below) to determine if participants were experiencing symptoms with intensity and frequency consistent with PTSD. Scores obtained on the CAPS were not used for inclusion/exclusion decisions. Instead, DSM-5 diagnostic criteria were used to determine clinical appropriateness for this study.

PTSD Checklist for DSM-5 (PCL-5)

The PTSD Checklist for DSM-5 (PCL-5; Blevins, Weathers, Davis, Witte, & Domino, 2015) is a 20-item self-report that assesses the 20 symptoms of PTSD in accordance with DSM-5 diagnostic criteria. The PCL-5 is frequently used for monitoring symptom change and screening for PTSD. Symptom severity scores range from 0-80, with each item being rated 0 (none) to 4 (all the time). The PCL-5 was administered for all participants as a PTSD screening measure. Those who scored above a 33 (Wortmann et al., 2016) were further assessed via the CAPS by the principal investigator.

Quick Smell Identification Test (QSIT)

The QSIT (Sensonics, Inc., Haddon Heights, NJ) is a 3-item, forced-choice test that uses microencapsulated odorant strips to determine olfactory function (Doty, Shaman, Kimmelman, & Dann, 1984) and is capable of detecting unsophisticated malingering, partial anosmia, and total anosmia. The QSIT allows researchers to identify individuals who possess abnormal olfactory function that may otherwise confound experimental results.

State-Trait Anxiety Inventory (STAI)

The State-Trait Anxiety Inventory (Spielberger, 1983) is a 40-item, self-report measure designed to measure both the transient state of arousal subjectively experienced as anxiety and the more constant emotional presence of anxiety. It has good psychometric properties (Speilberger & Vagg, 1984) and has a response burden of approximately ten minutes. The STAI assesses items based on a four-factor structure comprised of two primary factors: state anxiety and trait anxiety. Items on the STAI range from “I am Calm” (State Anxiety) to “I worry too much over something

that doesn't matter" (Trait Anxiety). The trait anxiety portion of the STAI served as a covariate for trait anxiety.

Igroup Presence Questionnaire (IPQ)

The Igroup Presence Questionnaire is a 14-item self-report questionnaire designed to measure presence utilizing a 7-point Likert scale (Schubert et al., 2001) that loads onto three subscales; spatial presence (the sense of physically being in the virtual environment), involvement (focus on the VE and involvement experienced), and experienced realism (subjective realism of the VE). The involvement and experienced realism subscales may be particularly relevant to exposure therapy as VR seeks in engage patients in a realistic way. Items range from "How aware were you of the real world while navigating in the virtual world?" to "How real did the virtual world seem to you?" IPQ scores were the primary outcome measure for this study.

Immersive Tendencies Questionnaire (ITQ)

The Immersive Tendencies Questionnaire (Witmer & Singer, 1998) is a 29-item self-report measure designed to assess individual tendencies towards immersing in different mediums, such as books, television, and video games. The items in this questionnaire measure the participant's involvement in many different daily activities, such as watching television, reading books, or enjoying movies. As involvement can result in more immersion, those who become more involved may also have greater immersive tendencies. The ITQ served as a covariate in presence-related analyses unless otherwise indicated.

Presence Visual-Analogue Scale (PVAS)

Participants were asked to rate their level of immersion during the experiment to determine presence on a visual-analog scale (VAS). Visual analog scales have been demonstrated to accurately assess anxiety (Davey, Barratt, Butow, & Deeks, 2007). It has been shown that VASs have moderate to strong correlations with Likert-based items (Hasson & Arnetz, 2005). VASs have superior metrical characteristics than discrete scales and can have a wider range of statistical methods applied to their measurements (Reips & Funke, 2008).

Presence Rating Scale (PRS)

Participants were asked to rate their current level of presence during scripted events within the exposure task. This rating was on a 7-point Likert scale to remain consistent with the Likert scale of the IPQ. The question, "How present do you feel?" was anchored at one (not at all) and seven (very much). The PRS was assessed verbally as to minimize the disruption of assessing presence during an experimental task, which can actually reduce perceived presence if done in an intrusive manner (such as visually).

Simulator Sickness Questionnaire (SSQ)

The Simulator Sickness Questionnaire was developed by Kennedy, Lane, Berbaum, and Lilienthal (1993). It is a 16-item self-report scale used to rate common symptoms of simulator sickness on a 4-point scale. Such symptoms include general discomfort, headache, eyestrain, sweating, and vertigo. Information about the user's present state of health was solicited before and after utilizing the VR equipment to assess symptoms commonly associated with VR use. The SSQ was used to ensure participant health was not compromised as a result of research participation.

Electrodermal Activity (EDA)

EDA measures the electrical conductance of the skin, which is made possible by sweat glands controlled by the sympathetic nervous system. EDA was used as an objective measure of psychophysiological activity and was assessed utilizing a Mindware MW3000A Bio-Potential and EDA Monitor. Silver-chloride cup electrodes were placed on the nondominant palm in accordance with best practices (Carlson, 2013). Data were collected with BioLab Acquisition Software and inspected visually during the experiment by either the principal investigator or a research assistant trained by the principal investigator. After the experiment, the signal was amplified 10x and processed through a 1 Hz Low Pass filter to remove artifacts caused by movement. All physiological data were inspected, corrected, and analyzed in EDA (Mindware Technologies LTD, Gahanna, OH) by the principal investigator. EDA served as an objective, physiological indicator of anxiety and sympathetic nervous system activation. Skin Conducance Reactions (SCRs) were defined as a 0.05uS increased between between 1-3 seconds post event.

Heart Rate Variability (HRV)

HRV is perhaps most simply described as the variation between heartbeat intervals. In recent years, HRV has been utilized as a selective index of parasympathetic control (compared to EDA, which is widely under sympathetic control). We assessed activation of both the sympathetic and parasympathetic influences on the autonomic nervous system to gain insight regarding the olfactory stimuli physiological influence. HRV was assessed with a MW3000A Bio-Potential Monitor. HRV served as a second objective, physiological indicator of anxiety, with less variability indicating an increased parasympathetic response. Specifically, respiratory sinus arrhythmia (RSA) was assessed, which is the naturally occurring variation in heart rate

during the breathing cycle. RSA serves as a measure of parasympathetic nervous system (PNS) activity. High-Frequency Power (HF/RSA Power) was used as a frequency-domain measurement to observe the 0.15 to 0.4 Hz band, which is thought to indicate PNS activity.

Odorant Ratings (Intensity, Valence, Familiarity)

Subjects were asked to rate the intensity, valence (pleasantness), and familiarity of the odorants using a 7-point Likert scale anchored at -3 (Extremely Unpleasant) to 3 (Extremely Pleasant). Intensity (Undetectable, Intolerable) and familiarity (Unfamiliar, Very Familiar) were rated on a similar 7-point scale.

Qualitative Feedback

Military participants were asked to provide feedback about the virtual environment. Specifically, they were prompted to provide insight into the degree to which the VE was consistent with their actual experience. This feedback allowed us to determine which aspects of the VE were effective and which elements may be improved upon for future research. Elements are deemed ineffective if they were distracting, out of place, incorrect, or otherwise detracted from the user experience.

Procedures

Informed consent was obtained by approved study personnel prior to participation as approved by the University of Central Florida (UCF) Institutional Review Board. Confidentially and its limits was reviewed prior to the pre-screen assessment as well as prior to experimental participation. Rights, including the right to withdraw, were discussed to ensure subjects understood prior to data collection. Participants were provided ample time to ask questions during informed consent and throughout each stage of the experiment if needed.

Following consent, subjects were asked to complete self-report measures and demographic questionnaires on an Amazon Fire 7" tablet (Amazon Inc, Seattle, WA.) They were then connected to the MW3000A physiological recorder and equipped with the VR equipment. After the experimenters ensured all systems were functioning correctly, volunteers were given a five-minute baseline period to familiarize themselves with the HMD and the VE. After this baseline period, they were informed that the experiment would begin momentarily and given the following set of instructions:

> *We are going to begin. During the experiment, we are going to present you with a virtual reality scene. Elements of the environment will be described to you in detail. Your job is to imagine yourself in the environment exactly as it is presented. Please remain focused on the scene; particularly, do not imagine anything that would make you feel more comfortable or relaxed. At certain points, you will be asked to rate how much you feel you are immersed in the environment or in other words, how much you feel you are really there. We will use the 1 to 7-point scale where 1 is "not at all" and 7 is where you feel "completely" immersed. When you are asked for your rating, try to give me the rating as truthfully and as quickly as possible. Your rating is very important. You will be notified when the experiment is over and given further instructions. Do you have any questions before we begin?*

Baseline physiological data was collected during a discrete 5-minute period. The last 60 seconds of the baseline window was utilized as a control for physiological analyses to control for individual differences. Physiological data was collected continuously over the duration of the 8-minute exposure simulation, as seen in Figure 4.

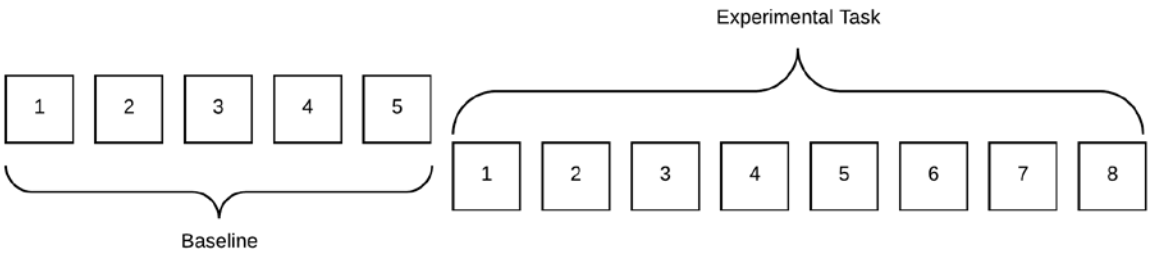


Figure 4: Experimental Task Timeline

Virtual Reality System

The odorants used were ceramic pellets impregnated with scented oil (Dreamreapers Inc., Melrose Park, IL). Scents were those commonly utilized in exposure therapy for combat-related PTSD, including diesel fuel, garbage, smoke, and body odor. Air charged with odorants was delivered via air dispersion by a USB controlled Scent Palette (Virtually Better Inc., Decatur, GA). During the experimental trial, 50% (n = 30) of participants received odorants congruent with the VE; the other half (n = 31) of participants did not receive odorants.

The VE (Bravemind, Institute for Creative Technologies, USC, Pasadena, CA) was modeled in 3D and controlled with the Unity3D engine (Unity Technologies, San Francisco, CA) and approximated a military convoy as it traveled through urban and rural environments approximating those of Iraq and Afghanistan. Participants were asked to imagine that they were on a convoy mission which included visual and auditory cues such as burning trash, ambient

noises, and other environmental factors. The VE was presented to the subject using a Sony HMZ-T3 HMD (Sony Corp., Tokyo, Japan) and high-fidelity stereo headphones (Audio Technica ATH-M50x; Audio Technica, Stow, Ohio). The VE was presented by a PC with an Intel® i5-4670 3.4 GHz CPU, 16 gigabytes of RAM, and a Nvidia® GTX 780 Tic GPU. Participants were navigated through the VR environment at a pace matched to auditory descriptions of the scene. Participants did not have navigational control of their avatar for this experiment. Scripted events were presented to add realism to the VE. For example, a helicopter and A10 Thunderbolt flew over participants with a matching audio sample. Later, a burning vehicle on the side of the road was displayed as the participant passes an urban environment. For those in the odorant condition, this scene was augmented with the scent of smoke. Upon completion of the VE task, participants were assisted out of the physiological and VR equipment and then asked to complete questionnaires regarding their experience within the VR. Upon completing these questionnaires, volunteers received either SONA credit or an Amazon gift card as compensation, concluding their participation in this study.

RESULTS

Statistical Analyses

All statistical analyses were conducted on the final sample (n = 61) using JMP Pro 13.0.0 (SAS Institute Inc., Cary, NC) after screening for data normalcy. All analyses defined significance with a p-value ≤ 0.05 unless otherwise specified. All Linear Mixed Models (LMMs) utilized a Kackar and Harville (1984) correction to reduce bias and correctly estimate standard errors for the utilized sample size.

Data Screening

Jackknife distance measures were calculated to identify multivariate outliers utilizing the critical value formula recommended by Penny (1996). Two such outliers were found with critical values greater than 3.82. All analyses were conducted with outliers both included and excluded to assess their influence on the mixed model. These analysis comparisons showed that while outliers had a small impact upon significance p-values, they did not possess enough influence to alter the significance of any analyses. Thus, the outliers were included in the results reported here.

To detect group differences in age, a one-way ANOVA was used which revealed statistically significant differences between participant groups, $F(3,56) = 15.97$, $p < 0.0001$. A Tukey-Kramer HSD was used to further delineate where these group differences were while protecting the analysis error rate, and showed that the military/veteran groups were both significantly older than their respective civilian control groups. No differences were found between odorant condition groups for either the Veteran or Control groups. Age values for each group can be seen in Table 2.

Table 2: Age Differences by Group

Group	*n*	Mean	Std Error	Lower 95%	Upper 95%	
1. Veteran - Odorant	11	32.0909	2.1999	27.684	36.498	A
2. Veteran - No Odorant	14	35.2143	1.9981	31.213	39.215	A
3. Control - Odorant	19	20.5789	1.6739	17.226	23.932	B
4. Control - No Odorant	17	19.3529	1.7696	15.808	22.898	B

Note: Groups not connected by the same letter are significantly different.

Chi-Square tests were then utilized to explore demographic differences between groups. With respect to ethnicity, no significant differences were found (χ^2 18, n = 61,) p = 0.53. Significant differences were found for level of education (χ^2 9, n = 61,) p = 0.002, with veterans having completed more bachelor and graduate degrees than the civilian sample. Significant differences were also found with respect to marital status (χ^2 6, n = 61,) $p < 0.0001$, with veterans being married and divorced significantly more than the civilian, student population. A significant difference was also found for ITQ scores, $F(3,57) = 2.913$, p = 0.042, which suggested veterans

were less likely to experience presence as seen in Figure 5.

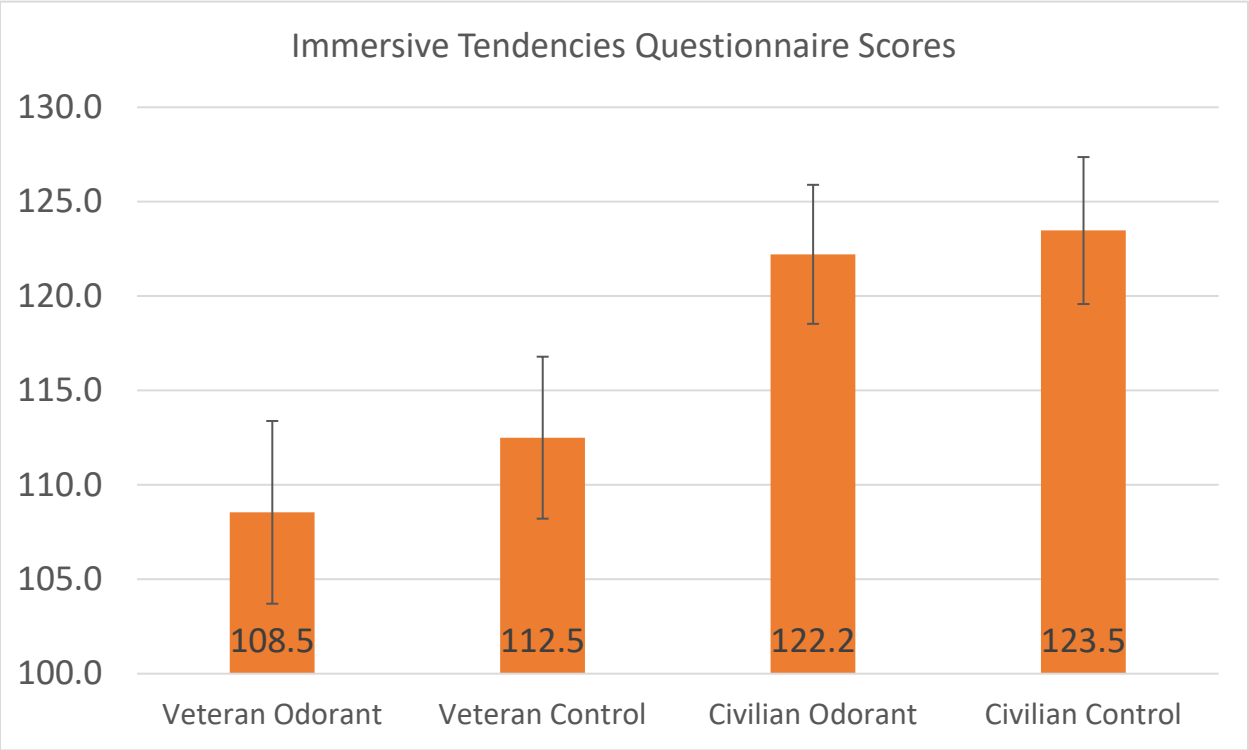


Figure 5: IPQ Scores by Group

Preliminary Analyses

A series of *t*-tests were conducted comparing the odorant and no-odorant military groups to isolate the effect of odorant on users' sense of presence consistent with clinical use of VR with odorants in the treatment of combat-related PTSD (Beidel, Frueh, Neer, & Lejuez, 2017). No significant differences were found between odorant conditions, indicating those with military backgrounds experienced similar levels of presence regardless of odorant condition, $t(23) = -0.134$, $p = 0.894$. These results were mirrored in the civilian groups as well, with odorants failing to make a significant difference in reported presence on the IPQ, $t(34) = -1.35$, $p = 0.179$.

Physiological data recorded over the duration of the VE was divided into eight sequential 60-second epochs (henceforth referred to as 'time'), with Respiratory Sinus Arrhythmia (RSA)

and High Frequency/RSA Power (HF/RSA) Power as the primary dependent variables. Veteran RSA was examined utilizing a full factorial model to identify differences between service members who received odorants compared to those who did not. This model revealed no significant differences between odorant conditions, $F(1, 21.98) = 1.269$, $p = 0.272$. EDA was also explored within the military groups and results indicated no significant differences in EDA between odorant conditions, $F(1, 21.93) = 0.680$, $p = 0.418$. Taken together, these findings indicated that within those subjects with military experience, odorants did not appear to make any significant difference in physiological functioning, which ran counter to this study's *a priori* hypotheses. The combined IPQ scores can be seen in Figure 6. Thus, more complex analyses were then conducted to further contrast potential differences that may be attributed to odorant or participant experience.

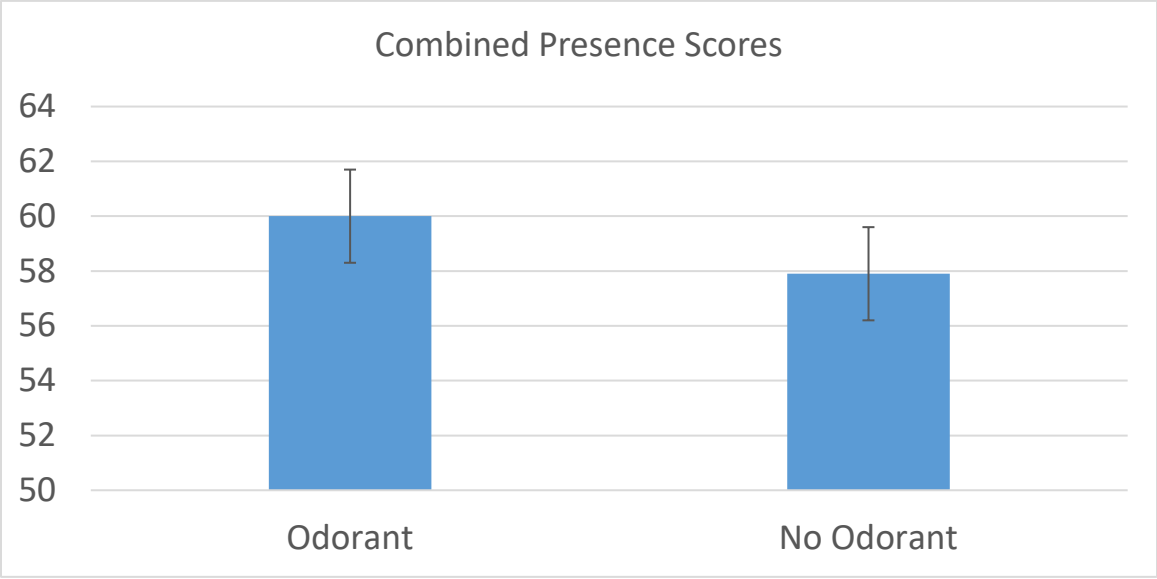


Figure 6: Combined IPQ Scores

Full Model Analyses

Presence

The first scientific aim of this study was to determine if the delivery of odorants increased perceived presence for the entire duration of the VE task. A 2x2 ANCOVA examining presence scores on the IPQ, while covarying for scores on the ITQ, failed to find statistically significant differences between those who received odorants and those who did not, $F(4, 56) = 0.965$, $p = 0.329$, $r^2 = 0.11$. This result indicated that statistically, each group experienced similar levels of presence regardless of odorant condition. Presence ratings on the VAS were also examined utilizing an identical ANCOVA. While this result was closer to reaching statistical significance ($F(4, 56) = 1.959$, $p = 0.167$, $r^2 = 0.10$), definitive differences were absent. Examination of group means did reveal a pattern of scores consistent with H_1, with those receiving odorants reporting greater presence (*LSM* = 69.89, *SE* 3.79) than those who did not receive odorants (*LSM* = 62.57, *SE* = 3.59).

A 2x2 ANCOVA was then utilized to explore the IPQ subscales that include Spatial Presence, Involvement, and Realism. No significant differences were found for Spatial Presence ($F(4, 56) = 1.258$, $p = 0.29$, model $r^2 = 0.08$) or Involvement ($F(4, 56) = 0.532$, $p = 0.71$). A significant difference for background was found when examining Realism ($F(4, 56) = 8.597$, $p = 0.004$) which indicated that those with a military background perceived the VE to be more realistic (*LSM* = 17.43, *SE* = 0.79) than their civilian peers (*LSM* = 14.31, *SE* = 0.65) regardless of odorant condition.

Three scripted events were included within the virtual environment which included (1) passing a grove of palm trees, (2) an RPG attack on the lead vehicle of the convoy, and (3)

crossing beneath a potentially hostile bridge. Participants were prompted after each event during the VE to verbally provide their current presence rating on a scale of 1-7 (seven being "most there"). For the palm grove event (event one), no significant effects for odorant ($F(4, 55) = 0.668$, $p = 0.417$) or the background*odorant interaction ($F(4, 55) = 1.646$, $p = 0.204$) were found, though a main effect for background approached significance ($F(4, 55) = 3.29$, $p = 0.074$). Analysis of the second event, which depicted an enemy RPG strike against the first vehicle immediately ahead of the participants vehicle, showed a statistically significant main effect for background ($F(4, 56) = 7.546$, $p = 0.008$), indicating that those with military backgrounds perceived higher presence ($LSM = 5.65$, $SE = 0.22$) during this event than the controls ($LSM = 4.82$, $SE = 0.11$). Event three (passing under a potentially hostile bridge) had comparable results to event one, with both odorant and the background*odorant interaction effects failing to meet statistical significance. The background condition approached significance ($F(4, 56) = 3.425$, $p = 0.0695$) with participants with military backgrounds reporting higher levels of presence ($LSM = 5.19$, $SE = 0.25$) compared to controls ($LSM = 4.57$, $SE = 0.20$).

Physiological Responses

Heart Rate Variability (HRV)

Linear Mixed Modeling (LMM) was used to explore the effects of odorants and military background on HRV, with lower HRV indicating more arousal. A main effect for background was identified, $F(1, 55.97) = 4.707$, $p = 0.035$, $r^2 = 0.81$, which showed veterans had significantly less variation ($LSM = 6.08$, $SE = 0.22$) during the interbeat period than controls ($LSM = 6.84$, $SE = 0.20$). This result suggested that veterans experienced more arousal than the

civilian controls when engaged with the VE. Full model effects can be seen in Table 3. A main effect for time was also found, $F(1, 55.97) = 2.823$, $p = 0.007$, as seen in Figure X.

Table 3: RSA Main Effects

			$r2 = 0.81$
Main Effect	**DF**	**F Ratio**	**p**
Background	1	4.707	0.034
Odor	1	0.379	0.541
Time	7	2.823	0.007
Background*Odor	1	1.776	0.188
Background*Time	7	0.864	0.535
Odor*Time	7	0.932	0.481
Background*Odor*Time	7	0.675	0.693

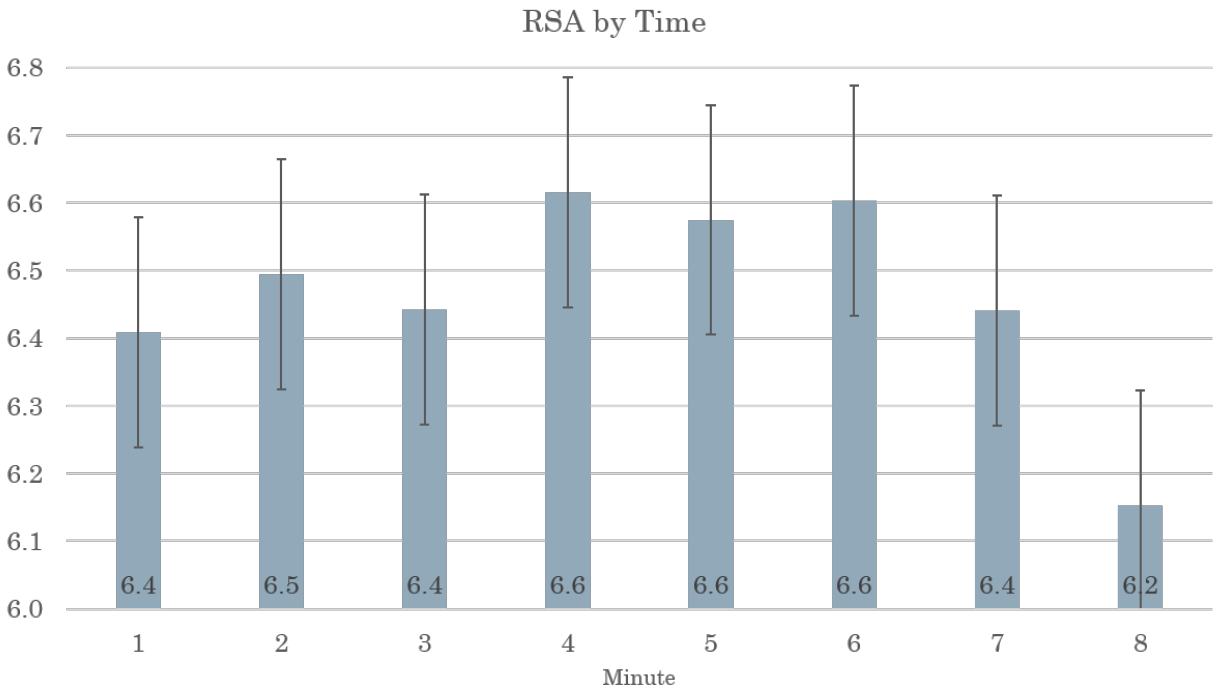


Figure 7: RSA by Time

RSA was then examined using the 60-second, post-scripted time, the results of which can be seen in Table 4.

Table 4: RSA Effects by Scripted Event

Effects, Event 1	**Sum of Squares**	**F Ratio**	**p**
Odorant	2.846	2.323	0.133
Background	5.666	4.624	0.035
Background*Odorant	7.167	5.849	0.018
Effects, Event 2			
Odorant	0.271	0.143	0.705
Background	9.004	4.772	0.033
Background*Odorant	0.464	0.246	0.621
Effects, Event 3			
Odorant	0.978	0.756	0.388
Background	7.354	5.686	0.02
Background*Odorant	1.922	1.486	0.227

Significant effects for background and the background*odorant interaction were found immediately following event one. Following this event, veterans displayed significantly lower RSA (*LSM* = 6.18, *SE* = 0.22) than controls (*LSM* = 6.81, *SE* = 0.18). The background*odorant interaction indicates that the veteran group who did not receive odorants was significantly more aroused than the control groups, though statistically similar to the veteran odorant condition, as seen in Table 5.

Table 5: Background*Odorant RSA Interaction for Event 1

Group	**Least Sq Mean**	**Std Error**	
Veteran, Odorant	6.76	0.333	A
Veteran, No Odorant	5.607	0.307	A
Civilian, Odorant	6.682	0.253	B
Civilian, No Odorant	6.944	0.268	B

Note: Groups not connected by the same letter are significantly different.

A main effect for background was also seen immediately following event two ($F(3, 56) = 4.772$, $p = 0.033$), during which veterans again showed significantly lower RSA (*LSM* = 6.04, *SE* = 0.28) than controls (*LSM* = 6.83, *SE* = 0.22). This pattern of responding continued following event three ($F(3, 56) = 5.686$, $p = 0.020$), with veterans displaying lower RSA (*LSM* = 6.25, *SE* = 0.23) than their control counterparts (*LSM* = 6.97, *SE* = 0.18).

High Frequency/ Respiratory Sinus Arrhythmia (HF/RSA) power was also examined to identify differences in parasympathetic activation between groups and conditions. LMM was again utilized to explore the background, odorants, background*odorant interaction, and baseline HF/RSA effect terms. This model had an R^2 of 0.44, accounting for 44% of the variance within the model. The *a priori* hypothesis stated that both those with military backgrounds, those who received odorants, and the military background/odorant group, would experience greater parasympathetic activation. This hypothesis was not supported by the data, as odorant condition ($F(1, 55.22) = 0.013$, $p = 0.908$, $r^2 = 0.41$), background ($F(1, 55.11) = 0.407$, $p = 0.526$), and the odorant*background interaction ($F(1, 55.11) = 0.086$, $p = 0.769$) failed to reach statistical significance. Further examination of the LSM for the odorant condition revealed marginally higher HF/RSA peak power in those who received odorants (*LSM* = 0.19, *SE* = 0.006) compared to those who received no smells (*LSM* = 0.18, *SE* = 0.006). Inspection of HF/RSA also revealed minute differences favoring those without military backgrounds (*LSM* = 0.19, *SE* = 0.005) over their service member counterparts (*LSM* = 0.18, *SE* = 0.006). These main effects can be seen in Table 6.

Table 6: HF/RSA Effects

Main Effect	df	F Ratio	*p*
Background	1	0.387	0.536
Odor	1	3.034	0.087
Segment Number	7	0.745	0.633
Background*Odor	1	0.318	0.574
Background*Segment Number	7	0.919	0.491
Odor*Segment Number	7	0.682	0.686
Background*Odor*Segment Number	7	1.775	0.09

Electrodermal Response (EDA)

Significant group differences were identified in baseline tonic SCL between those with military service and their civilian counterparts, $t(58) = 2.430$, $p = 0.018$, as seen in Figure 8.

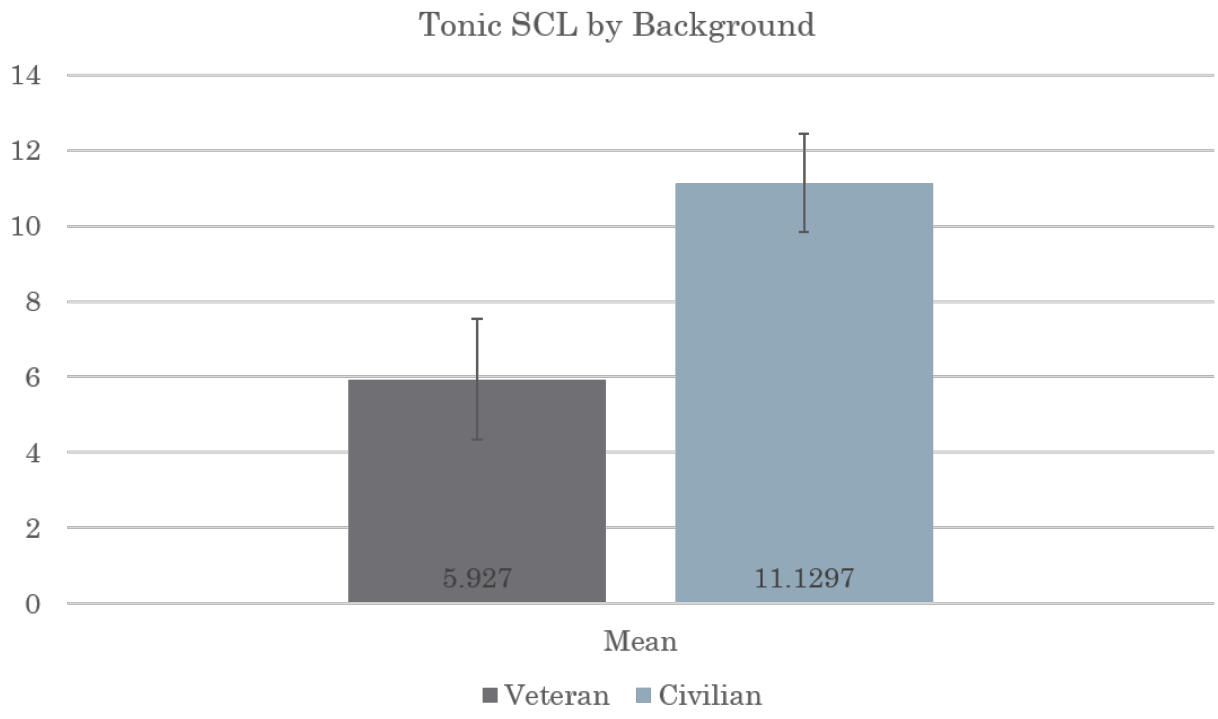


Figure 8: Baseline Tonic SLC by Group

Time segments utilized for RSA and HF/RSA were also examined to determine if differences existed within the electrodermal response, this study's index of sympathetic nervous system activity. A LMM was constructed which accounted for baseline response levels, odorant condition, military background, and time. When examining total SCR responses, regardless of the presence or absence of a scripted event, no significant differences were seen for odorant condition ($F(1, 54.93) = 0.913$, $p = 0.343$), background ($F(1, 54.95) = 0.069$, $p = 0.793$), or the interaction term ($F(1, 54.87) = 0.010$, $p = 0.918$, Table 7). This model had an $R^2 = 0.77$ and indicated that participants across conditions, backgrounds, and exposure time had similar numbers of total SCR events, though it is probable that the constant carries the majority of the accounted residual. No SCRs included in this model were classified as Event-Related.

Table 7: Total SCRs

Effect	**df**	**F Ratio**	***p***
Background	1	0.069	0.793
Odor	1	0.913	0.343
Segment	7	30.137	<0.000
Background*Odor	1	0.01	0.918
Background*Segment	7	0.846	0.549
Odor*Segment	7	2.687	0.01
Background*Odor*Segment	7	1.569	0.142
Total SCRs, Baseline	1	98.453	<0.000

Tonic Skin Conductance Level (SCL) was also examined to determine if odorants or background influenced mean SCL after removing artifacts introduced by SCRs. This analysis utilized the same LMM as total SCR but with SCL set as the dependent variable. After controlling for baseline measurements, no significant effects were found as seen in Table 8. These results indicate that regardless of background or odorant condition, similar levels were

observed. Tonic Period was also assessed to determine if participants varied in the *duration* of SCR responses utilizing this LMM. These results were not statistically significant and indicated similar tonic periods regardless of condition or background as seen in Table 9.

Table 8: Tonic SCL Effects and Interaction Term Across VE

Term	DF	DF Error	F Ratio	p
Background	1	55.04	0.2	0.656
Odor	1	55.03	0.218	0.642
Background*Odor	1	55.03	2.356	0.13

Note: Model $R^2 = 0.98$

Table 9: Tonic Period Effects and Interaction Term Across VE

Term	DF	DF Error	F Ratio	p
Background	1	55.21	1.225	0.273
Odor	1	55.2	0.044	0.833
Background*Odor	1	55.16	0.002	0.964

Note: Model $R^2 = 0.77$

15-second time segments where analyzed utilizing a LMM. Significant main effects for Odorant, $F(1,56) = 4.43$, $p = 0.039$ ($r^2 = .99$), and Background, $F(1,56) = 5.83$, $p = 0.019$ were identified, which suggested those who received odorants had higher SCL than those without as seen in Table 10. Further, veterans had lower SCL than their civilian counterparts

Table 10: Post-Event SCL

Effect	*df*	DFDen	*F* Ratio	*p*
Odor	1	56	4.439	0.039
Background	1	56	5.832	0.019
Event	2	112	1.92	0.151
Odor*Background	1	56	2.046	0.158
Odor*Event	2	112	0.456	0.634
Background*Event	2	112	0.893	0.412
Odor***Background***Event	2	112	0.010	0.989

Note: Model $R^2 = 0.05$

Table 11: Mean SCL, Scripted Events

Term	DF	DF Error	F Ratio	p
Background	1	55	0.271	0.604
Odor	1	55	1.311	0.257
Background*Odor	1	55	2.56	0.115

Note: Model $R^2 = 0.99$

Table 12: Tonic Period, Scripted Events

Term	DF	DF Error	F Ratio	p
Background	1	55	5.369	0.024
Odor	1	55	2.837	0.098
Background*Odor	1	55	0.39	0.535

Note: Model $R^2 = 0.99$

Tonic Period was analyzed as seen in Table 12. A significant main effect was found for background, which indicated that those with military backgrounds spent significantly less time without phasic EDA ($LSM = 7.6_{sec}$, $SE = 1.666$) compared to controls ($LSM = 12.5_{sec}$, $SE = 1.353$). In other words, service members' SCRs occurred over longer periods of time, but at similar magnitudes, as controls. The main effect for odorants and the background*interaction term were not statistically significant.

EDA was also examined pre- and post-event do identify potential differences in SCL immediately before and after an event. 15-seconds before and after (30 seconds total) were analyzed via LMM. Significant effects were found for odorants and background, but not for time. These results indicated that those with military backgrounds had lower SCL, and those who received odorants, had greater levels of SCL (Table 13). SCL trends were also examined across time by group. These are seen in Figure 9.

Table 13:Pre/Post Event SCL

Effect	*df*	Error	F Ratio	*p*
Odor	1	56	4.474	0.038
Background	1	56	5.962	0.017
Time	1	56	2.746	0.103
Odor*Background	1	56	2.087	0.154
Odor*Time	1	56	0.430	0.514
Background*Time	1	56	2.322	0.133
Odor*Background*Time	1	56	0.703	0.405

Note: $r^2 = 0.98$

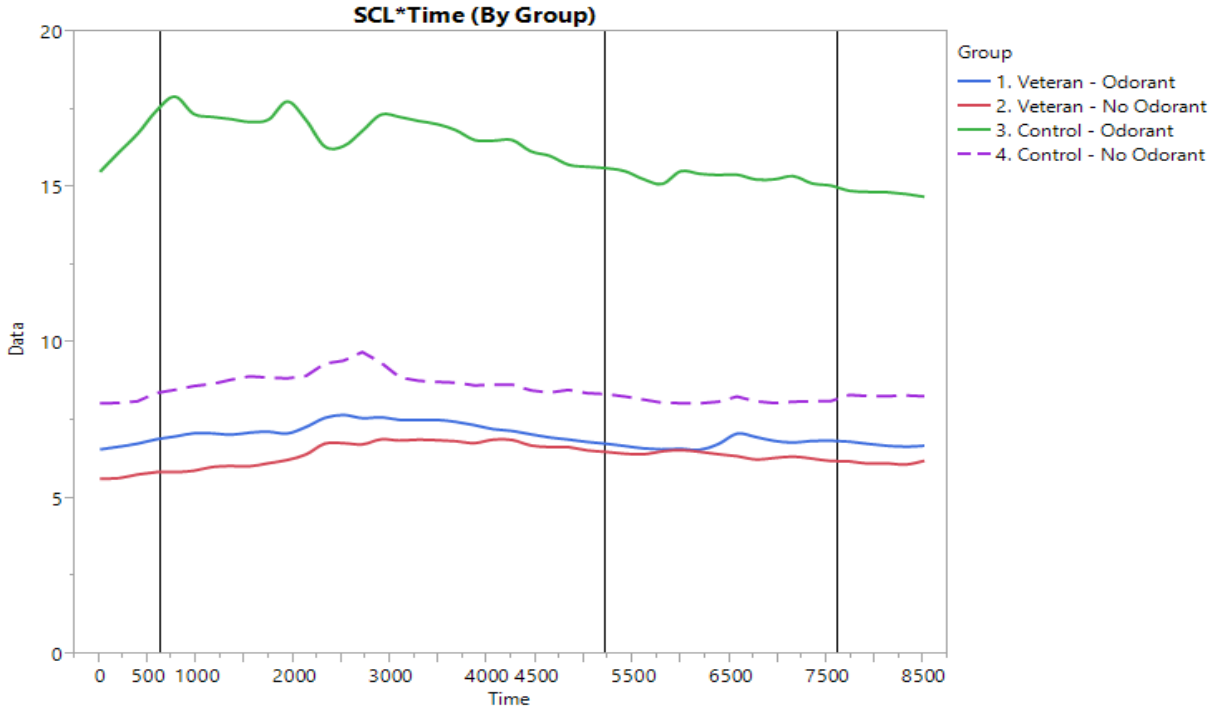


Figure 9: SCL Across Time

Note: Vertical lines represent events one, two, and three, respectively.

A more complex pre/post event mixed model was also run to examine the effects of odorants and experience immediately before and after the scripted events. This analysis utilized

resampled data (20hz, or 20 samples per second) for ten seconds immediately before and after each scripted event as seen in Table 14.

Table 14: EDA Event Analyses

Event 1 Effects (r squared = 0.98)	**DF**	**DFDen**	**F Ratio**	**Prob > F**
Background	1	57.29	9.186	**0.004**
Odor	1	57.29	5.076	**0.028**
Event 1 Effects	1	54.49	0.000	0.985
Time	1	54.84	0.325	0.571
Background*Odor	1	57.29	2.519	0.118
Background*Event 1	1	54.49	0.636	0.429
Background*Time	1	54.84	0.001	0.976
Odor*Event 1	1	54.49	0.154	0.696
Odor*Time	1	54.84	0.030	0.864
Event 1*Time	1	54.51	0.004	0.948
Background*Odor*Event 1	1	54.49	0.142	0.708
Event 2 Effects (r squared = 0.98)	DF	DFDen	F Ratio	Prob > F
Background	1	57	6.740	**0.012**
Odor	1	57	3.846	**0.055**
Time	1	57.1	2.926	0.093
Event 2	1	57.08	0.462	0.500
Background*Odor	1	57	2.438	0.124
Background*Time	1	57.1	0.205	0.652
Background*Event 2	1	57.08	1.708	0.197
Odor*Time	1	57.1	0.108	0.744
Odor*Event 2	1	57.08	0.868	0.355
Time*Event 2	1	57.1	0.154	0.696
Background*Odor*Event 2	1	57.08	0.884	0.351
Event 3 Effects (r square = 0.99)	DF	DFDen	F Ratio	Prob > F
Background	1	57.03	6.105	**0.017**
Odor	1	57.03	4.954	**0.030**
Time	1	56.77	0.000	0.998
E3	1	56.75	0.432	0.514
Background*Odor	1	57.03	2.897	0.094
Background*Time	1	56.77	0.037	0.849
Background*E3	1	56.75	0.076	0.784
Odor*Time	1	56.77	1.384	0.244
Odor*E3	1	56.75	0.888	0.350
Time*E3	1	56.82	0.153	0.697
Background*Odor*E3	1	56.75	0.238	0.628

Statistically significant main effects were observed for background and odorant conditions, but were absent across interactions with the dichotomous event (E*n*) marker, suggesting no differences were observed as the resulting factor combination. These significant

differences also suggested odorants resulted in increased presence, and that civilians experienced greater EDA than those with military service, which was consistent with previous analyses.

Event 1					
	Least Sq Mean	Std Error		Least Sq Mean	Std Error
Odorant	12.359	1.580	Veteran	6.595	1.679
No Odorant	7.444	1.504	Civilian	13.207	1.392
Event 2					
Odorant	12.070	1.646	Veteran	6.888	1.751
No Odorant	7.610	1.568	Civilian	12.792	1.451
Event 3					
Odorant	12.694	1.693	Veteran	7.202	1.801
No Odorant	7.489	1.613	Civilian	12.980	1.492

MANCOVA

In order to fully investigate relationships within our model, multiple MANCOVA analyses were conducted on the main RSA and HRV datasets, which can be seen in Table 14.

Table 15: Physiological MANOVAs

Total SCRs	**df**	**Error**	**F Ratio**	**P**
Intercept	1	53	107.454	<.0001
Background	1	53	0.948	0.334
Odorants	1	53	1.023	0.316
Background*Odorants	1	53	3.156	0.081
Mean SCL	**df**	**Error**	**F Ratio**	**P**
Intercept	1	53	67.601	<.0001
Background	1	53	5.95	0.018
Odorants	1	53	2.951	0.091
Background*Odorants	1	53	1.968	0.168
Tonic SCL	**df**	**Error**	**F Ratio**	**P**
Intercept	1	53	67.163	<.0001
Background	1	53	5.842	0.019

Odorants	1	53	3.009	0.088
Background*Odorants	1	53	1.968	0.166

RSA	**df**	**Error**	**F Ratio**	**P**
Intercept	1	53	1646.559	<.0001
Background	1	53	3.333	0.073
Odorants	1	53	0	0.996
Background*Odorants	1	53	2.09	0.154

HF/RSA	**df**	**Error**	**F Ratio**	**P**
Intercept	1	53	952.859	<.0001
Background	1	53	0.68	0.413
Odorants	1	53	3.635	0.062
Background*Odorants	1	53	0.205	0.652

As with the LMM, general statistical support was observed for a background main effect. Odorants did not reach statistical significance in these analyses. Relationships between pre- and post-experimental STAI scores were examined as well to determine if anxiety correlated with physiological responses, as seen in Tables 15 and 16, respectively.

Table 16: Pre-Exposure STAI/Physiological Correlations

	Pre Exposure	**1**	**2**	**3**	**4**	**5**	**6**
1	STAI Pre Exp	1.00					
2	Total SCRs, Seg 1	-0.02	1.00				
3	Tonic SCL, Seg 1	-0.14	0.66	1.00			
4	Mean SC, Seg 1	-0.13	0.67	1.00	1.00		
5	RSA, Seg 1	-0.22	-0.22	-0.12	-0.11	1.00	
6	HF/RSA Peak Power, Seg 1	-0.26	-0.03	0.11	0.10	0.10	1.00

Table 17: Post Exposure STAI/Physiological Correlations

	Post-Exposure	1	2	3	4	5	6
1	STAI Post Exp	1.00					
2	Total SCRs, Seg 1	-0.10	1.00				
3	Tonic SCL, Seg 1	-0.17	0.66	1.00			
4	Mean SC, Seg 1	-0.17	0.67	1.00	1.00		
5	RSA, Seg 1	-0.22	-0.22	-0.12	-0.11	1.00	
6	HF/RSA Peak Power, Seg 1	-0.09	-0.03	0.11	0.10	0.11	1.00

Secondary Analyses

Anxiety

Trait Anxiety scores on the STAI were examined to identify any group differences prior to principle analyses. An ANOVA examining STAI-Y2 (trait anxiety) did not find statistically significant differences between groups ($F(3, 57) = 1.388$, $p = 0.255$). These results indicate that each group had similar levels of trait anxiety as measured by the STAI prior to participating in the experimental task. A 2x2 ANCOVA was then utilized to detect differences in state anxiety before and immediately after engaging in the VE. This model used individual trait anxiety as a covariate and found the main effect for time approached significance, which indicated mild increases in anxiety following the VE task (*LSM* = 32.86, *SE* = 0.95) compared to baseline (*LSM* = 30.97, *SE* = 0.95.) No other effects approached or achieved statistical significance in this model as seen in Table 17.

Table 18: State Anxiety Fixed Effect Tests

Term	**DF**	**DF Error**	**F Ratio**	***p***
Background	1	56	2.790	0.100
Odor	1	56	1.224	0.273
Time	1	57	3.419	0.069
Background*Odor	1	56	1.674	0.200

Note: Model $R^2 = 0.78$

Odorant Valence, Familiarity, and Intensity

Prior to the experiment, participants were asked to rate each odorant in terms of familiarity, pleasantness, and intensity. A one-way ANOVA was used to identify significant differences by group. No significant differences were found between groups on pleasantness, familiarity, or intensity. P-values for these one-way ANOVAs can be seen in Table 18, with individual odorant means and standard errors in Table 19.

Table 19: One-way ANOVAs, Valence*Group

	Pleasantness	**Familiarity**	**Intensity**
		p	
Smoke	0.55	0.33	0.11
Body Odor	0.99	0.18	0.90
Diesel Fuel	0.24	0.67	0.16
Garbage	0.81	0.51	0.53

Table 20: Odorant Valence Means by Group

	Smoke						Body Odor					
Group	Pleasant	*SE*	Familiar	*SE*	Intense	*SE*	Pleasant	*SE*	Familiar	*SE*	Intense	*SE*
Veteran - Odorant	5.82	*0.45*	5.73	*0.46*	4.27	*0.29*	5.36	*0.30*	3.27	*0.35*	3.09	*0.27*
Veteran - No Odorant	5.36	*0.40*	5.21	*0.41*	5.07	*0.26*	5.29	*0.27*	3.14	*0.31*	3.21	*0.24*
Control - Odorant	5.00	*0.34*	5.16	*0.35*	4.32	*0.22*	5.32	*0.23*	2.53	*0.27*	3.00	*0.21*
Control - No Odorant	5.29	*0.36*	4.65	*0.37*	4.59	*0.23*	5.29	*0.24*	2.53	*0.28*	3.00	*0.22*
	Diesel Fuel						**Garbage**					
Group	Pleasant	*SE*	Familiar	*SE*	Intense	*SE*	Pleasant	*SE*	Familiar	*SE*	Intense	*SE*
Veteran - Odorant	4.09	*0.38*	4.00	*0.46*	4.45	*0.23*	7.27	*0.34*	5.45	*0.29*	11.00	*4.09*
Veteran - No Odorant	4.50	*0.34*	4.50	*0.40*	4.29	*0.20*	6.93	*0.30*	5.07	*0.26*	14.00	*4.00*
Control - Odorant	4.21	*0.29*	4.58	*0.35*	4.68	*0.18*	7.16	*0.26*	5.37	*0.22*	19.00	*3.58*
Control - No Odorant	3.59	*0.31*	4.12	*0.37*	4.88	*0.19*	7.29	*0.27*	5.59	*0.23*	17.00	*3.24*

Simulator Sickness

Simulator sickness was also examined to assess for new or worsening symptoms caused by the VR task. This was done by examining the effects of odorants, background, and time across the model. No significant differences were found for odorant condition ($F(1, 57) = 0.137$, $p = 0.712$) or the odorant*background interaction ($F(1,57) = 0.236$, $p = 0.628$). A main effect for background did approach significance ($F(1,57) = 3.970$, $p = 0.051$), indicating that those with military backgrounds reported a greater number of symptoms consistent with simulator sickness ($LSM = 4.2$, $SE = 0.86$) compared to the controls ($LSM = 1.95$, $SE = 0.72$). Previous research has shown that those with expertise in given situations may be more susceptible to SS (McGuinness, Bouwman, & Forbes, 1981).

Attention

After the simulated exposure task was completed, participants answered several questions about stimuli that may or not have been included within the VE. These stimuli were multimodal in nature and included visuals (a camel, helicopter, blue and white police vehicle, and collapsed bridge), tactile feedback (yes/no), odorants (yes/no), and temperature changes (yes/no). This battery of questions served as an index of attention as it is difficult to utilize objective measures of attention (such as eye trackers) with current HMD technology. Overall, 100% of participants correctly reported receiving visuals through the HMD. A large majority (81%) correctly identified they experienced tactile feedback during the EXP. Most participants (77%) across all groups reported receiving odorants, while only 30 participants were administered odorants during the EXP. Those who did not receive odorants were far more accurate in determining if they been administered odorants than the actual odorant condition. Most individuals were also

correct in determining if they had been administered odorants (58%), while 62% correctly identified the presence of a white and blue police vehicle within the VE. Finally, all participants correctly identified that an object (a destroyed bridge) was not present in the scenario. The overall pattern of correct responses on the attention items indicated no significant differences in attention between groups. These results indicated all groups exerted fair effort during the experimental tasks.

DISCUSSION

The primary purpose of this study was to determine if odorants or military experience influenced users' perceived presence during a virtual convoy in a Middle Eastern environment. The *a priori* hypotheses were that the administration of odorants, a positive history of military deployment, and the interaction of the two, would result in significantly higher levels of presence. Further, it was hypothesized that odorants and military experience would moderate HRV and EDA.

The hypotheses regarding presence were not supported by the data collected in this sample. Regardless of the presence or absence of odorants, participants experienced similar levels of presence during the simulator exposure task. Scores on the VAS mirrored these results. Individual group means did *trend* in the hypothesized directions with those who received odorants reporting an average of two points higher on the IPQ, and seven points on the VAS. However, subscale analysis of the IPQ differed from previous research, which indicated significantly different scores on the involvement subscale, favoring odorants (Munyan, Neer, Beidel, & Jentsch, 2015). Those with military service also reported substantially higher levels of realism after engaging with the VE. Increasing realism may be beneficial during psychotherapy if incremental improvements in CS realism translate to improving treatment outcomes. It is possible that the observed significant effects described here accounted for enough variance within the model that further effects would require additional power to detect. Raw mean analysis of group*odorant effects trended in the hypothesized directions but were not statistically significant. Another hypothesis is that the groups were more dissimilar than planned.

Despite previous anecdotal and empirical evidence favoring odorants, significant effects were far more likely to be attributed to military experience within this sample. Regarding

presence, main effects for a military background were found during the second scripted event (an RPG ambush) during which those with deployment experience were more present than controls. This was unexpected as we believed those with combat experience might be more critical of the VE. It is possible warfighters were particularly engaged with this event because of their experience. The urban environment may have been a "red flag" for those who have deployed, whereas those without military training did not differentiate between environments and their associated (and simulated) risk despite the included narration during the task.

Examination of HRV also showed those who had deployed previously had significantly less variation during the interbeat period, indicating significantly more parasympathetic arousal than controls. While there was moderate support of our military background hypotheses, HRV analyses failed to statistically support the hypothesis that odorant would moderate RSA. We also hypothesized electrodermal responses of both greater magnitude and frequency in those who receive odorants and in participants with military experience. The data collected did not support either of these hypotheses. In fact, the only main effect that achieved statistical significance was tonic period, which indicated service member's responses, though similar in frequency, had longer durations than controls. This may be a result of military training or diverse levels of vigilance throughout the VE. Unfortunately, this study lacked temporal resolution that would enable causal inferences. The lack of significant EDA differences may also be (to some degree) a lack of state anxiety generated by the VE. Despite scripting several potentially dangerous events into the VE (RPG Ambush, potential IED sites, and roadside debris), which are often specifically associated with danger in contemporary combat zones, reported anxiety was less than anticipated.

The lack of anxiety response within the military population may be because all military participants had engaged in convoy operations overseas, some with multiple deployments. This degree of experience may have blunted an anxiety response for many reasons. For example, participants may have realized that no dangerous outcome was physically possible given the simulated nature of the VE. Another reason for this finding may be that those with more time deployed had habituated to anxiety associated with military operations. This hypothesis was tested utilizing a bivariate analysis, which did not show a significant relationship between time deployed and state anxiety during the VE. The nature of our nonclinical sample may also be a factor; those with PTSD (and perhaps, the most to fear) were excluded from this study, which may introduce a ceiling effect with respect to anxiety.

An important theoretical question also lingers; is presence required for exposure therapy to work? Imaginal EXP has been demonstrated to be effective repeatedly, without the use of virtual reality of other external stimuli. When done correctly, it is likely that presence is high and is thus a byproduct of the exposure when patients are actively engaged during therapy. Our hypotheses suggested that the addition of odorants to EXP might further increase presence, thus boosting patient engagement, with the hopes that increased engagement via presence may then result in tertiary effects, such as improved outcomes or shorter episodes of care. A similar trend was currently found by Mota et al. (2015), who noted that ratings of vividness during EXP predicted treatment outcome. A valid concern regarding the inclusion of odorants is that odorant specificity may be subject to the “uncanny valley” (Mori, 1970), by which incorrect stimuli may produce effects worse than no stimulant at all. Further research may be required to explore odorant specificity as it relates to EXP.

Participants also rated odorant valences as a part of this study, with all groups rating each quality (pleasantness, familiarity, and intensity) in a similar fashion. Despite measuring odorant valence and individual differences in immersive tendencies, statistical evidence supporting anecdotal statements encountered throughout the combat-related PTSD literature was not found. While this study did find limited evidence that odorants increase presence and moderate RSA and EDA, these findings were not statistically robust enough to drive clinical decision-making. There are, however, several ways to methodologically improve upon this study in the future.

Limitations and Future Directions

In this study, veteran participants were nearly a decade older on average than the nonmilitary controls within this sample. Further, the military sample was also more likely to be married and have completed more formal education. While some difference in age was expected due to the nature of military service, which requires at least an 8-year commitment (only some of which must be active duty), we did not anticipate a mean difference of greater than 10 years. The differences between groups may also be less obvious. For instance, it is estimated that 5.2% of the US population has served in the armed forces (Chalabi, 2015). It has also been shown that soldiers are more likely to come from high-income areas and have completed more education than civilian peers . SES data were not collected during this study, nor would it be appropriate to readily interpret educational differences that existed between groups within this sample, as all control subjects were actively pursuing degrees at an institution of higher education. While no research could be identified that offered a theoretical rationale for age or education influencing presence, the possibility cannot be ruled out. An improved approach might include recruiting adults closer in age, which may then better account for both educational and marital differences

and better represent the broader adult population rather than the college population described here.

It was also noted that 33% of participants were unable able to correctly identify if odorants were delivered during their experimental task. While "true negative" participants were more accurate identifying the absence of odorants, it is possible the odorants utilized where insufficient in duration or intensity during the task for certain individuals which may have impacted presence ratings. Similarly, no ratings of odorant fidelity were collected to determine if participants perceived the odorants as scene appropriate. Increased presence would likely only occur if odorants were high fidelity with respect to the VE.

Temporal resolution within the study was also insufficient to permit additional analyses of interest. For example, comparing physiological responses during odorant administration or narrative delivery may have been revealing. Due to equipment limitations, "flagging" these events during the experiment was not possible.

Thus far, the terms "memory," "experience," and "background" were used interchangeably. This was not in error, but rather an attempt to honestly convey the rift between internal and external validity whilst "bootstrapping" military participants' deployment experience overseas to an artificial virtual environment to assess what we believed to be a somewhat common military mission. This "muddying of the waters" was unavoidable with a nonclinical sample who may not have *experienced* and *perceived* a convoy operation *precisely* as simulated during the exposure task. With a true clinical sample utilizing VEs designed around their specific traumatic event would likely experience significantly greater levels of anxiety and presence. Specifically, matching trauma-related odorants to trauma-focused therapy eliminates

the problems inherent in a well design, internally valid research study where findings may not generalize outside of the laboratory. Given the highly personal nature of PTSD, one might argue that sacrificing internal validity (by customizing odorant/trauma scenes to each subject) would lead to significantly more meaningful data (which would be difficult to control for, statistically speaking).

Utilizing a clinical sample of individuals with actual traumatic, episodic memories and customizing the VE to match their individual event may be the only method to accurately assess the effect of odorants due to the number of variables involved in memory formation. Further, contrasting the clinical groups to similar military controls would be a significant improvement, as it would allow further control to distinguish between the effects of military training, deployment experience, and trauma. While this research design would be complex, the results may be more meaningful given the variability seen in PTSD diagnoses and mental health in general. This research would also serve as a meaningful leap towards exploring the true field value and utility of odorant augmentation during exposure therapy.

Conclusion

Exposure therapy continues to be a first-line intervention for anxiety and trauma-related disorders. Exposure therapy is already being augmented with virtual reality with great success (Beidel et al., 2017). However, the specific effects of odorants remain relatively underexplored. The contrast between odorant conditions in this study may have improved with groups better matched for age and education, with further emphasis on external validity. Despite the limitations of this study, several noteworthy findings were discovered. Those with military backgrounds reported the VE to be more realistic, which may prove to have utility given the

importance of realism during EXP. Further, service members also experienced more decreased RSA than controls, indicating that VEs alone may improve performance during exposure. It is our hope that clinicians and researchers alike will continue to embrace VE augmentation and research, and that future research addresses and overcomes the challenges discussed here.

APPENDIX A: IRB APPROVAL LETTER

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Approval of Human Research

From: **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To: **Benson Munyan**

Date: **October 18, 2017**

Dear Researcher:

On 10/18/2017 the IRB approved the following human participant research until 10/17/2018 inclusive:

Type of Review:	IRB Continuing Review Application Form Expedited Review Category #4, 6, &7
Project Title:	Odorants and presence in warfighters: Do the scents of war matter?
Investigator:	Benson Munyan
IRB Number:	SBE-16-12531
Funding Agency:	
Grant Title:	
Research ID:	N/A

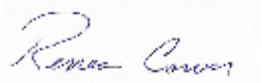
The scientific merit of the research was considered during the IRB review. The Continuing Review Application must be submitted 30days prior to the expiration date for studies that were previously expedited, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at https://iris.research.ucf.edu .

If continuing review approval is not granted before the expiration date of 10/17/2018, approval of this research expires on that date. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

All data, including signed consent forms if applicable, must be retained and secured per protocol for a minimum of five years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained and secured per protocol. Additional requirements may be imposed by your funding agency, your department, or other entities. Access to data is limited to authorized individuals listed as key study personnel.

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., UCF IRB Chair, this letter is signed by:



Signature applied by Renea C Carver on 10/18/2017 10:15:32 AM EDT

APPENDIX B: OUTCOME VARIABLE CORRELATIONS

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	ITQ	1.00															
2	IPQ	-0.03	1.00														
3	IPQ (SP)	-0.02	0.86	1.00													
4	IPQ (Involvement)	0.05	0.65	0.46	1.00												
5	IPQ (Realism)	-0.06	0.79	0.47	0.27	1.00											
6	STAI (State, Post)	-0.21	0.34	0.22	0.20	0.35	1.00										
7	STAI (State, Pre)	-0.30	0.20	0.15	0.08	0.23	0.70	1.00									
8	STAI (Trait)	-0.13	0.09	0.06	0.02	0.14	0.63	0.83	1.00								
9	SSQ (Pre)	-0.19	0.22	0.11	0.24	0.18	0.47	0.56	0.49	1.00							
10	SSQ (Post)	-0.15	0.33	0.16	0.26	0.35	0.73	0.58	0.52	0.84	1.00						
11	Anxiety (Pre)	-0.19	0.20	0.04	0.14	0.29	0.76	0.72	0.68	0.46	0.61	1.00					
12	Anxiety (Post)	-0.16	0.40	0.27	0.28	0.37	0.81	0.53	0.45	0.43	0.65	0.75	1.00				
13	Video Game Use	0.25	-0.04	0.00	-0.01	-0.07	-0.25	-0.14	-0.22	-0.19	-0.27	-0.21	-0.26	1.00			
14	Palm Grove	0.04	0.55	0.47	0.43	0.37	0.19	0.23	0.21	0.10	0.09	0.20	0.24	-0.09	1.00		
15	RPG Ambush	-0.02	0.64	0.50	0.35	0.56	0.24	0.08	-0.04	0.14	0.22	0.14	0.34	-0.19	0.71	1.00	
16	Bridge Rating	-0.05	0.57	0.48	0.42	0.39	0.31	0.20	0.12	0.23	0.27	0.21	0.36	-0.13	0.72	0.70	1.00

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