

Effects of semantically irrelevant virtual reality experience on memory and emotion after watching a traumatic event

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Table of Contents

Original Manuscript..... 5

Supplementary Files..... 21

 Figures 22

 Figure 1..... 23

 Figure 2..... 24

 Figure 3..... 25

 Figure 4..... 26

 Figure 5..... 27

 Figure 6..... 28

 Figure 7..... 29

 TOC/Feature image for homepages 30

 TOC/Feature image for homepage 0..... 31

Effects of semantically irrelevant virtual reality experience on memory and emotion after watching a traumatic event

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Abstract

Background: First responders play crucial roles for protecting citizens and communities from various hazards. Due to the high-stress nature of their work, first responders suffer significant mental health issues. Existing mental health interventions, albeit their benefits, do not target cognitive processing of traumatic events such as memory and emotion.

Objective: As a novel attempt using immersive virtual reality, the current work aims to examine effects of a semantically irrelevant virtual reality (SIVR) content to intervene in the retrieval of an adverse event memory and associated emotion.

Methods: A total of 107 participants were recruited in the experiment and randomly assigned to one of three groups: Control Group, Comparison Group, and Intervention Group. In Stage-1, participants in all groups watched a short video of a house fire. In Stage-2, Control Group stayed seated without doing anything. Comparison Group read a text paragraph about Egyptian Ocean, as semantically irrelevant follow-up information. Intervention Group watched a 360° VR video of Egyptian Ocean. Positive And Negative Affect Schedule survey was administered each after the two stages. In Stage-3, the memory accuracy of the house fire video was assessed using a forced recognition test of 15 pairs of a true image and a fake image, generated by AI software.

Results: One-way ANOVA revealed no difference of the memory accuracy between three groups. However, repeated measures ANOVA found that the SIVR experience significantly boosted positive emotion of Intervention Group participants and reduced negative feelings of participants in all groups.

Conclusions: Our findings suggest that SIVR serves as a quick and affordable way to address psychological reaction after watching a traumatic event. Future research is required to generate the memory suppression effect of the SIVR content.

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Original Manuscript

Introduction

First responders play crucial roles for protecting citizens and communities from various hazards. A first responder refers to an individual responsible for protecting life, property, and environment in the early stage of various incidents [1]. Such incidents include fire, medical emergency, vehicle crash, hazardous materials release, and natural disaster. Once these incidents occur, first responders such as firefighters, police officers, and emergency medical technicians are deployed to the scene to mitigate impacts of the incidents [2].

Emergency response is a high-risk task that places severe stress on first responders. The intense burden is incurred by witnessing human deaths and sufferings; running risk of harm and violence to themselves; overwhelming workload due to physically-demanding tasks and long work hours; and making life-and-death decisions under time pressure [3].

Harsh nature of emergency response led to significant safety and health problems among first responders. The rate of occupational injuries and illnesses for US firefighters was more than three times higher than that for all other occupations [4]. Particularly, first responder's mental health issues are at an alarming level. Nearly 50% of police officers who responded to 9/11 terrorist attack suffered from severe depression, anxiety, and posttraumatic stress disorder (PTSD) [5]. Over 20% of medical responders of the Great East Japan Earthquake were diagnosed with clinical depression [6]. Astonishingly, 50% of US firefighters have had suicidal ideation or attempts in their careers [7].

To tackle the mental health issues among first responders, several psychological interventions were available. Critical Incident Stress Debriefing (CISD) was employed to share the reaction and emotion after witnessing a traumatic event, [8,9]. Nonetheless, the effectiveness of the CISD was either insignificant or weak [10]. Mindfulness meditation aimed to slow down racing and negative thoughts [11]. While mindfulness meditation resulted in improvement in one's mood after the practice, its psychological impact did not sustain for a longer period [12]. In addition, Difede et al. [13] provided first responders to the 9/11 terrorist attack with cognitive behavioral therapy (CBT), including psychoeducation, breathing exercise, imaginal exposure, and relapse prevention. Results showed significantly lower depression and PTSD survey scores than a non-CBT group. Essar et al. [14] administered Pre-Traumatic Vaccination (PTV) for search and rescue personnel

to prepare for anticipated traumatic events (e.g., warfare), and found that those who received the psychological vaccine reported lower levels of distress.

Despite the benefits of existing mental health treatment, limitations exist. Therapeutic techniques such as CBT and PTV are focused on increasing individual's general coping capacity for future traumatic events; therefore, they do not target specific causes of mental health symptoms nor account for psychological processes leading from causes to symptoms [15]. For example, deep breathing is intended to control autonomic nervous system functions, resulting in reduced heart rate and oxygen consumption [16]. Thus, the breathing technique has little to do with the individual's prior experience of a traumatic event. In addition, existing psychological interventions generate transient effects for a short period after the interventions [17]. Also, the effectiveness of psychological techniques such as debriefing and mindful meditation greatly depends on the recipient's commitment and seriousness toward the interventions [10]. In this regard, knowledge regarding human cognitive processes involving the memory and emotion of a traumatic remains limited. Our study aims to bridge this research gap by providing semantically irrelevant virtual reality (SIVR) content to suppress the retrieval of the memory of a traumatic event and to alter associated emotion.

Cognitive models of mental disorder posit that repeated re-experiencing of a traumatic event leads to negative symptoms such as hyperarousal, anxiety, and depression [18]. Fig. 1 illustrates one of the widely accepted cognitive models of PTSD [19]. A traumatic event is perceived by an individual via multiple sensory channels (e.g., visual, auditory) and stored in one's memory. The cognitive processing of the traumatic event is influenced by different factors such as the event characteristics (e.g., severity, uniqueness) and the individual's prior experience, beliefs, and coping behavior—both positive (relaxation, meditation, counseling) and negative (avoidance, anger, violent behavior, or use of alcohol)—related to the event.

Once the memory of the traumatic event was created, reexperiencing of the trauma occurs when current threats emerge as matching triggers. Matching triggers are the cues associated with the nature of the trauma such as similar situations such as lights and sounds. For example, if one experienced a severe fire event, one's exposure to other fires or bright light may trigger the memory of the prior fire. The perception of such similar threats retrieves the memory of the traumatic event and accompanies strong emotional reaction such as hyperarousal, fear, and anxiety [19]. Psychological reaction to the reexperience is also influenced by coping

strategies, either being positive or negative. When the individual person relies on negative coping strategies, the emotional symptoms develop into a more severe level of mental health disease such as depression and PTSD [20].

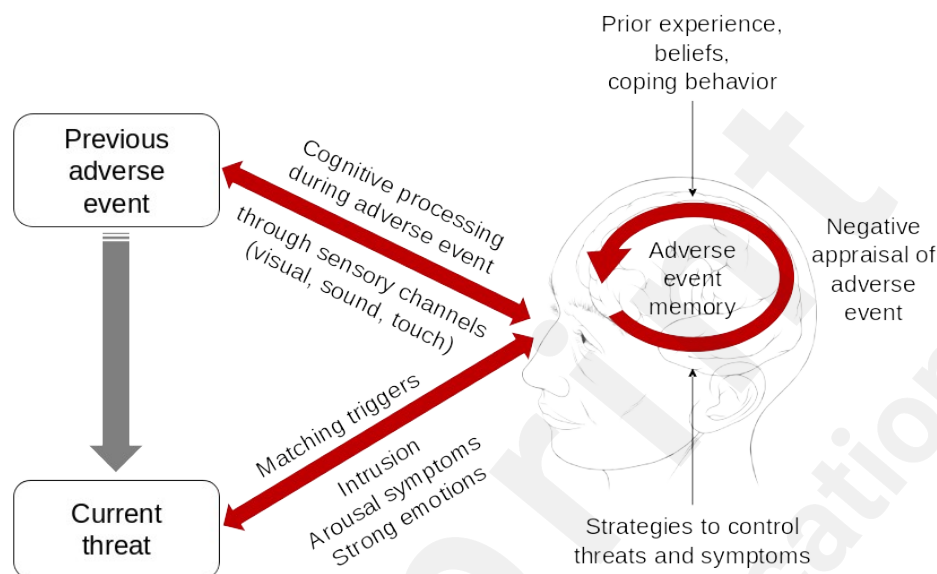


Fig 1. Cognitive model for memory and emotion of traumatic events (adapted from Ehlers & Clark [2000])

Given that the reexperience of a traumatic event is closely connected to the retrieval of associated memory, it is anticipated that if the memory retrieval gets suppressed, then the negative appraisal of the previous trauma and associated emotional reaction will be lessened. To generate the ‘memory suppression effect’, our study uses semantically irrelevant (SI) information as a follow-up intervention after an individual experiences a traumatic incident directly or indirectly. SI information refers to visual and auditory cues that are meaningfully distant from an initial experience of the trauma.

Semantically relevant information was widely used to produce the ‘misinformation effect’, which indicates the integration of false follow-up information into the memory of an initial experience. As a seminal work, Loftus et al. [21] discovered that participants’ initial memory of a car accident (occurring near a *yield* sign) was partially altered (occurring near a *stop* sign), due to the subsequent, false information that was semantically relevant. Following this work, numerous studies examined malleability of human memory that allows for integration of initial memory and following false information when two pieces of information are

semantically related [22]. Misinformation effect brought remarkable impacts on forensics and criminal justice where truthfulness of one's memory determines the guilt of crimes or offenses. Nevertheless, there is little knowledge regarding the effects of SI information, especially regarding its role for suppressing initial memory of a traumatic event and assuaging associated emotions.

There are several categories of semantical relationships between concepts [23]. In the current study, the antonymic or opposite relationships were used to render semantical irrelevance. For example, a residential house fire, a common emergency handled by first responder, has several representative attributes such as *fire*, *red*, *hot*, and *artificial structure*. Thus, SI contents have opposite qualities such as *water*, *blue*, *cool*, and *natural environment*, which are commonly available in tropical oceans.

VR offers an excellent environment that enables an immersive experience of the SI contents, in comparison with a 2-dimensional computer monitor. Indeed, previous research showed the effectiveness of VR for reducing psychological symptoms [24,25]. Nonetheless, the effects of the SIVR on the memory and emotion of a previous adverse event were seldom reported in the literature.

In addition to the 'memory suppression effect' of the SI experience, our study examines the 'virtual getaway effect' of a VR-based trip that relieves negative emotions induced from traumatic events. Prior studies found that a travel had a positive impact on reducing stress and depressive symptoms [26,27]. Considering the cost and time required for a physical travel, VR-based trips emerged as an easy, accessible means of taking a virtual getaway [28,29].

To this end, the objective of the current study is to investigate the memory suppression effect and the virtual getaway effect of SIVR experience as an intervention for mental health challenges commonly faced by first responders after they were exposed to a traumatic event.

Materials and Methods

A total of 107 participants were recruited from a large public state university in Texas between June 2023 and August 2023. To be eligible for the current experiment, participants must be at least 18 years old and currently enrolled in the institution. Those who currently work or previously worked as a first responder were excluded to control prior exposure to an abnormal level of emergency situations that typical civilians would

have not experienced in general. Also, those with mental issues such as depression and PTSD were excluded from the recruitment to control the baseline emotion. In addition, participants who have any fear or phobia of being underwater or motion sickness with VR were excluded. The mean age of the participants was 25 years (min=18, max=55, SD=6.00).

Participants were randomly assigned to one of the three groups: Control Group, Comparison Group, and Intervention Group as shown in Fig. 2. There was no significance difference in the age of the participants across three groups ($F(2, 104)=0.214, p=0.808$).

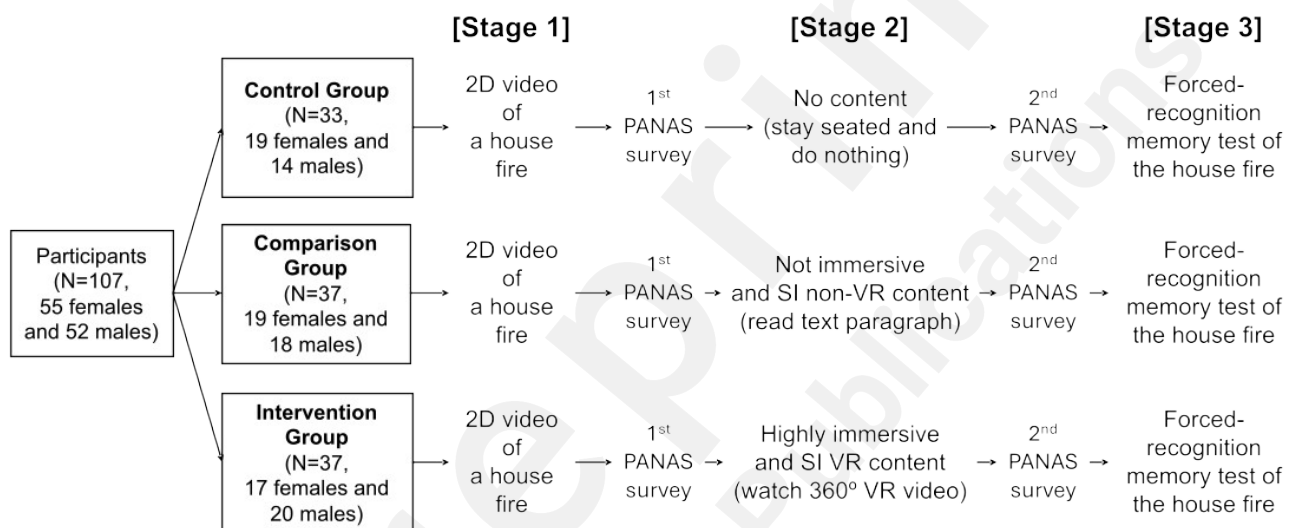


Fig 2. A three-stage experimental procedure

Participants followed a three-stage experimental protocol as shown in Fig. 2. In Stage-1, participants in all groups watched a three-minute video of a real house fire that occurred in a resident area in the US. A large TV monitor (diagonal size=65 inches) was used to display the video to increase the realism of the indirect witness of the fire. The video was recorded by a local fire department in 2019 and posted at YouTube shortly after. Fig. 3 shows different snapshots of the house fire video. The fire ruined a majority of the house and spread to a neighboring house.



Fig 3. Snapshots of the 2D video of a real house fire

After watching the house fire video, participants were randomly assigned to one of three conditions for Stage-2. Control Group participants did not do any task while staying seated for three minutes. Participants in Comparison Group read a text paragraph describing Egyptian Ocean as the following (abbreviated). The length of the text was adjusted to take about three minutes to be read.

“Egypt is an interesting destination in many ways: history and culture buffs can explore its ancient civilization, and beach vacationers can relax in its many resorts. One of them, Marsa Alam, is considered the best place in the country for snorkeling. [...] Its water area is rich in coral, fish and other underwater life. [...] Coral reefs are turtles' favorite environment: not only do they provide turtles with food, but also protect them from bad weather. Barely hatched from the egg, a baby turtle gains strength by eating jellyfish, sponges, and fish. [...]”

Participants in Intervention Group watched a three-minute 360° VR video of Egyptian Ocean that shows similar natural scenes described in the text paragraph. Fig. 4 shows snapshots of the VR video (source: AirPano). This VR video provides a live recording of underwater nature that contains sea animals and coral reef. The choice of Egyptian Ocean as a SIVR content was based on the opposite attributes of the underwater nature to the house fire in several representative aspects: red-blue (color), fire-water (element), hot-cold (temperature), and artificial structure-underwater nature (environment).

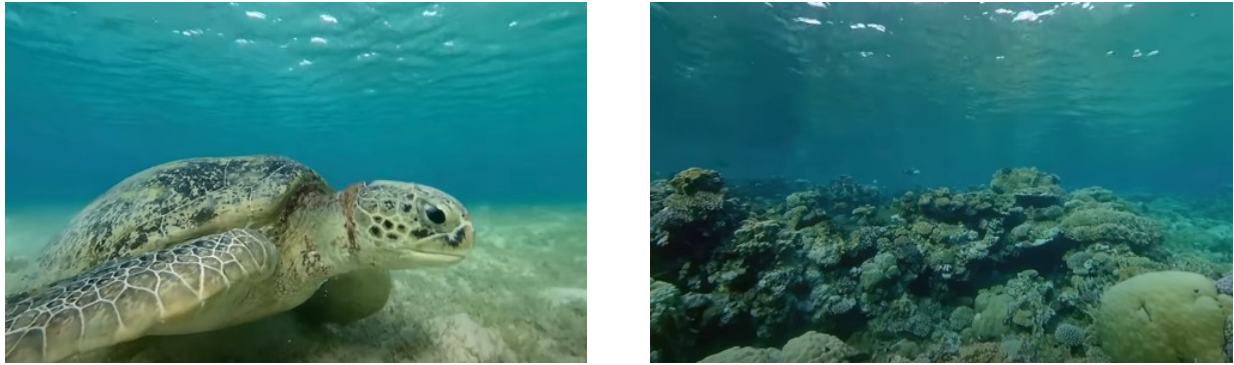


Fig 4. Snapshots of the 360°VR video of the Egyptian Ocean

In Stage 3, a forced-recognition test was conducted to assess memory accuracy of the house fire that participants in all three groups watched in Stage-1. A forced-recognition memory test, in which participants are required to choose one image from multiple options that they believe they saw it before. The forced-recognition test was widely used for memory-testing studies [30,31].

To make false images of the house fire video, we used Adobe Firefly [32], an image-generative AI program that recently became available to the public. This generative AI program has multiple features such as generative fill. An example of the fake images used in the forced recognition test is presented in Fig. 5.



Fig 5. An example of a true image and a fake image of the house fire. The image on the left is a true snapshot image from the fire video and the image on the right is a modified (fake) image using the generative AI software. In the fake image, the fire and the smoke near the house were replaced with another small car that has no fire damage.

A total of 15 pairs of a true image and a fake image were used in the forced-recognition test. Memory accuracy was calculated as shown in Eq. 1.

$$\text{Memory Accuracy} = \frac{\text{Number of correctly chosen images}}{15} \quad (\text{Eq. 1})$$

In addition to the memory accuracy, participant's emotions were assessed each after the first and second stage, using Positive And Negative Affect Schedule (PANAS) [33]. PANAS survey has 20 items, consisting of 10 positive emotion types (e.g., interested, enthusiastic) and 10 negative emotion types (e.g., distressed, upset) with a 5-point Likert scale (1=not at all to 5=extremely). Thus, the full score for each category (positive and negative emotions) is 50 points. PANAS was widely used in previous studies as an instrument to assess participants' emotional state [34,35].

The memory accuracy was analyzed with independent one-way analysis of variance (ANOVA) by the group. The memory accuracy data satisfied the assumptions of normality and equal variance for ANOVA. Levene's test indicated equal variance between the groups ($F(2, 104)=2.348, p=.101$). For the significant main effect, a post-hoc analysis using the Tukey's HSD) test was considered.

The differences of positive and negative PANAS survey scores between the groups along two stages were analyzed with two-way mixed factor repeated measures ANOVA. A significance level (p -value) of .05 was used for statistical significance. For all statistical tests, JASP (version 0.18.3, JASP Team, 2024) was used.

Results

For memory accuracy, there was no significant difference between three groups ($F(2, 104)=0.748, p=.476$). Mean memory accuracy was 0.714 (SD=0.125) for Control Group; 0.732 (SD=0.117) for Comparison Group; and 0.694 (SD=0.155) for Intervention Group.

Regarding positive emotion, Table 1 presents descriptive statistics for the mixed factors repeated measures ANOVA for the positive PANAS survey scores and Fig. 6 illustrates changes in positive emotion of the participants along the first two stages between groups.

Table 1. Descriptive statistics of the positive PANAS scores

Stage	Group	N	Mean	SD
1 st Positive PANAS	Control	33	24.649	7.595
	Comparison	37	26.242	8.972
	Intervention	37	26.757	9.124

Stage	Group	N	Mean	SD
2 nd Positive PANAS	Control	33	23.541	8.726
	Comparison	37	24.667	9.816
	Intervention	37	29.892	11.007

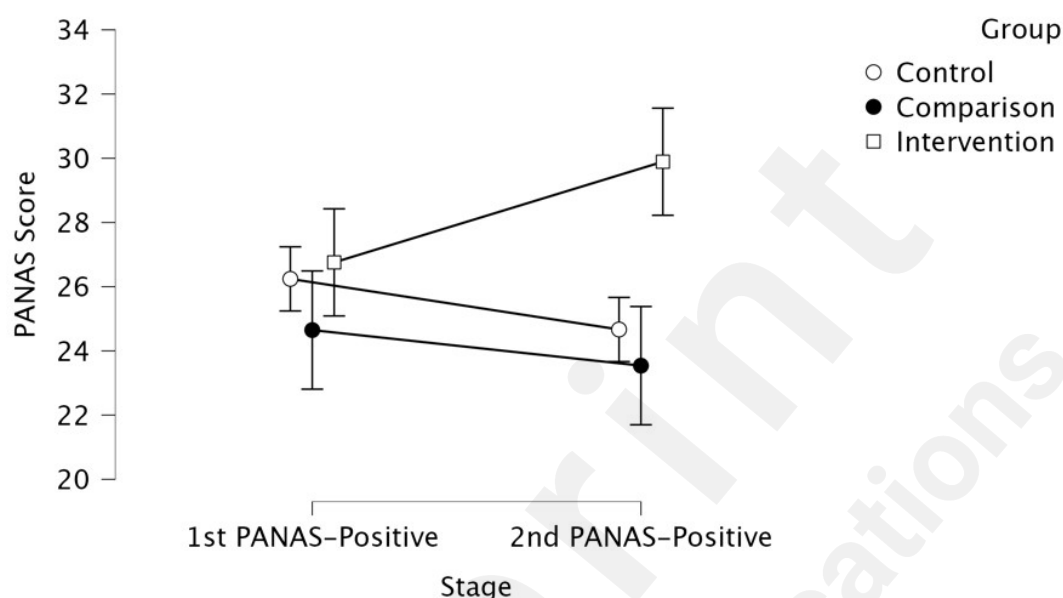


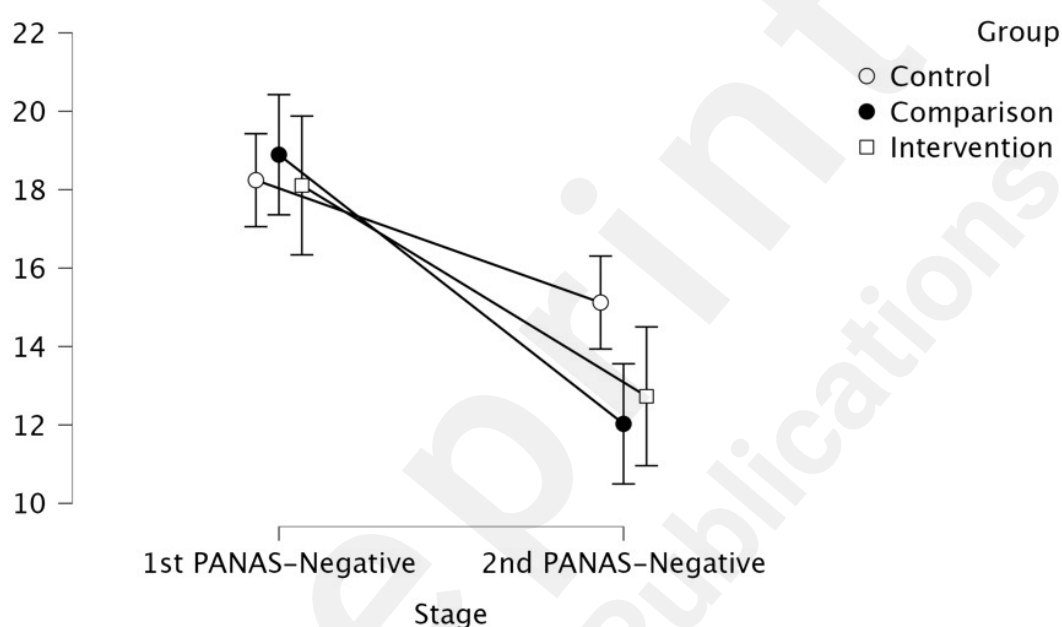
Fig 6. Mean positive PANAS scores between groups at the first and second stage with 95% CI

Regarding positive PANAS survey scores, there was no significant difference between the groups ($F(2, 104)=2.296$, $p=.106$) and between two stages ($F(1, 104)=0.056$, $p=.814$). However, we found significant interaction effect between the groups and the stages ($F(2, 104)=5.610$, $p=.005$, $\eta^2=0.013$). Post-hoc analysis revealed that positive PANAS score significantly increased only in Intervention Group between the two stages ($p=.051$) and that the second positive PANAS score of Intervention Group was significantly higher than that of Comparison Group ($p=.043$). All other interactions were not statistically significant.

Table 2 shows descriptive statistics of negative PANAS scores and Fig. 7 illustrates changes along the first two stages between groups. Results showed a significant change between the stages ($F(1, 104)=68.213$, $p<.001$). No significant main effect was found for the groups. Also, no significant interaction effect between the groups and the stages was found. Negative PANAS scores significantly decreased in Comparison Group ($p<.001$) and Intervention Group ($p<.001$). No other significant differences were found.

Table 2. Descriptive statistics of the negative PANAS scores

Stage	Group	N	Mean	SD
1 st Negative PANAS	Control	33	18.242	6.778
	Comparison	37	18.892	6.798
	Intervention	37	18.108	6.790
2 nd Negative PANAS	Control	33	15.121	3.050
	Comparison	37	12.027	5.781
	Intervention	37	12.730	4.350

**Fig 7.** Mean negative PANAS scores between groups at the first and second stage with 95% CI

Discussion

Findings from the current study showed that a SIVR experience (diving in Egyptian Ocean) boosted up positive emotion and lessened negative mood after indirectly witnessing an adverse event (watching a residential house fire). Such findings corroborate the remedial effects of a virtual trip, or 'a virtual getaway effect' derived from immersive VR environments [26,27]. Interestingly, reading text paragraph describing Egyptian Ocean also helped reduce negative emotion whereas participants in Control Group did not report any significant changes in positive emotion. The latter signifies needs for mental health support in any form, ranging from simple guided imagery training [36,37] to more interactive solutions like VR experiences [38]. Due to strong 'machismo' culture of public safety communities [39], responders tend to be reluctant to seek

counseling or external supports. Thus, SIVR experiences can act as an alternative approach compatible with the unique cultural traits among first responders thanks to its high accessibility.

It is noteworthy that even a short period (three minutes) of the virtual getaway resulted in significant changes in emotional state. Taking an actual vacation costs much time and money. Also, temporal gap between a trauma and the trip may be lengthy, making remedial effect of the trip weaker. Thus, virtual getaway using SIVR experience offers a quick and affordable way to address negative feelings after one was exposed to traumatic events. Now that diverse VR apps are available such as virtual concerts and sports events [40], there are more options to personalize VR experience as a psychological aid.

One methodological implication of the current work is the use of image-generating AI program (Adobe Firefly). Previous studies used simple drawings, photos, and verbal narratives to examine malleability of human memory [41,42]. Thanks to advanced AI technology, it takes now a few mouse clicks to create a false image that looks genuine. To our understanding, the current work is the first one that used a generative AI tool to create fake images used for a memory test. Considering rapid development of generative AI applications, the methodology established in the current study will inform future experiments that necessitate AI-generated artifacts.

Despite the novel benefits of SIVR experience on emotion, our study could not reveal the memory suppression effect, given the non-significant difference in the memory accuracy. Therefore, the relationship between the adverse event memory and associated emotion remains inconclusive. We suspect several reasons behind this lack of evidence.

First, the forced-recognition test may not be the best way to assess the memory accuracy of an initial event (a house fire). As shown in Fig. 5, only a limited number of items were modified (e.g., lawn under fire to a small car). In the house fire video, there are numerous elements that a participant could potentially catch or miss (e.g., flame, adjacent trees, firefighters, and houses). Thus, there was no guarantee that participants watched the items that were modified in fake images. If participants did not watch such, the recognition-based test becomes a binary choice with random chance. To address this issue, other methods to test one's memory need to be considered, for example, a recall-based memory test used in previous memory research [31].

Second, it is unclear that watching a house fire rendered sufficiently negative emotion. A house fire may

leave huge stress and suffering, if directly experienced. However, watching a house fire on a computer screen without any severe injuries and damages may not feel as traumatic, which may have weakened memory suppression effect of subsequent SIVR experience. In future studies, a stronger dosage of a traumatic event needs to be considered to create more distressing emotions. Relatedly, we did not assess pre-experiment emotional state, leading to limited manipulation check to see whether the house fire video made sufficient changes in viewers' emotion. Thus, future studies require pre-study assessment of participants' emotional state. In addition to self-reported surveys like PANAS [33], we recommend that physiological measures such as heart rate, skin conductance, or eye-tracking metrics be collected to find correlates with self-reported survey results.

Third, our study employed passive VR required to be watched only. Therefore, watching the VR video (Egyptian Ocean) may not have consumed much cognitive resource for attention and perception. It is speculated that if a participant uses more cognitive resources in VR environment, memory suppression effect and psychologically remedial effect would be stronger, making it more difficult to retrieve the memory of a prior traumatic event. Indeed, previous studies report that active VR requiring psychomotor activities consumed more cognitive resources [43,44]. Thus, future research needs to consider using active VR that consumes more cognitive and physical resources.

Other limitations of the current study need to be stated. Participants' baseline emotion before watching the house fire was not measured. Thus, it is not clear whether watching the house fire caused negative affect among participants beyond their pre-existing emotion. Our study used the PANAS survey, a self-reported and subject measure. Hence, physiological data such as heart rate, skin conductance, or eye-track would provide stronger evidence for the effect of SIVR. Additionally, longitudinal studies with multiple follow-up assessment are recommended to find long-term effects of SIVR on memory and emotion as the current study examined immediate effects only.

Conclusions

Our work showed promise of immersive SIVR as a novel solution to remedy mental health issues faced

by first responders. Although SIVR did not result in memory suppression effect, the current paper found significant effects of a virtual trip on both positive and negative emotion after indirectly witnessing an adverse event. Considering the prevalence of severe mental health issues among first responders and the paucity of mental health support for them, findings from the current study can inform quicker and more accessible solutions for psychological issues, in combination with existing mental health interventions.



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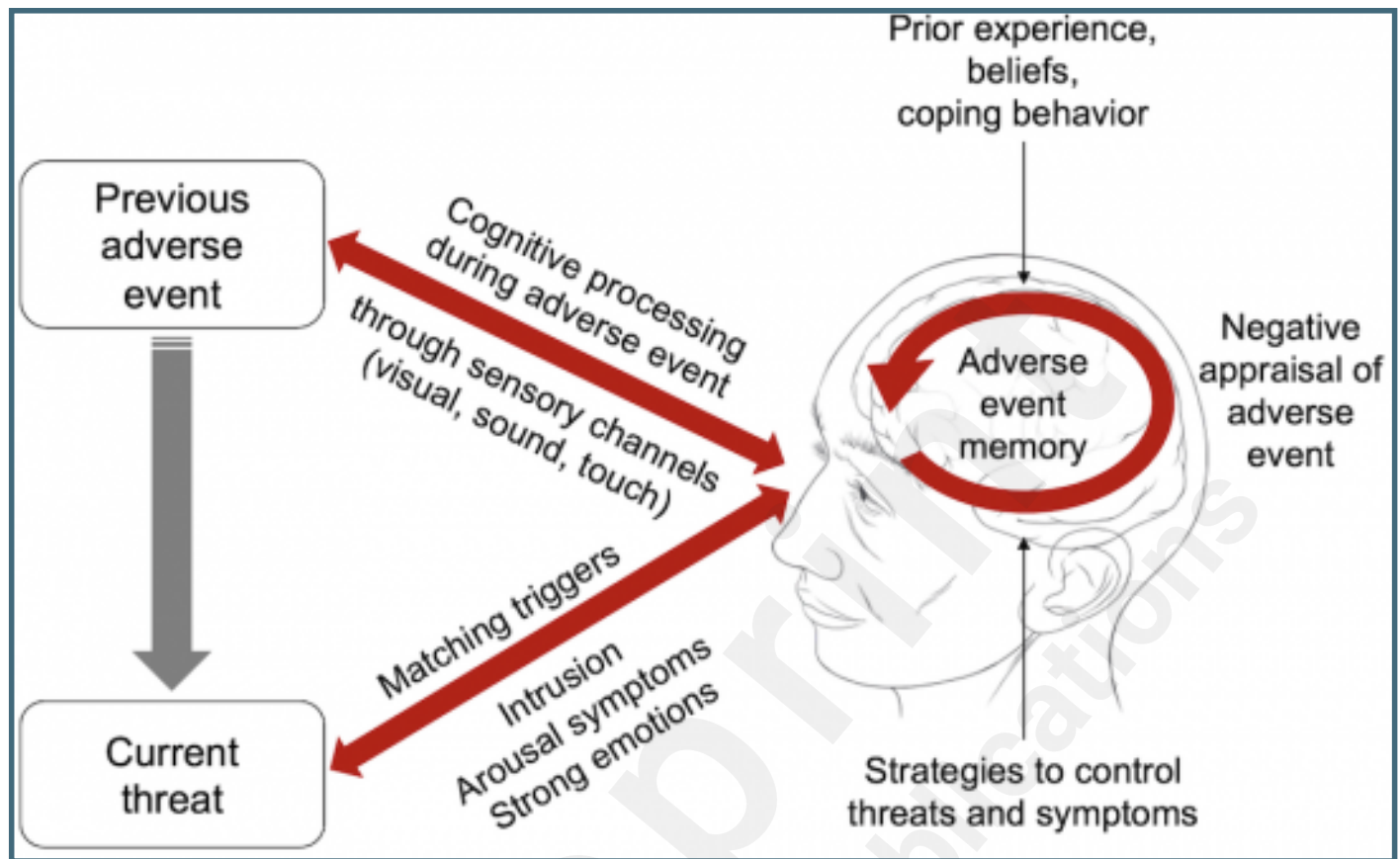
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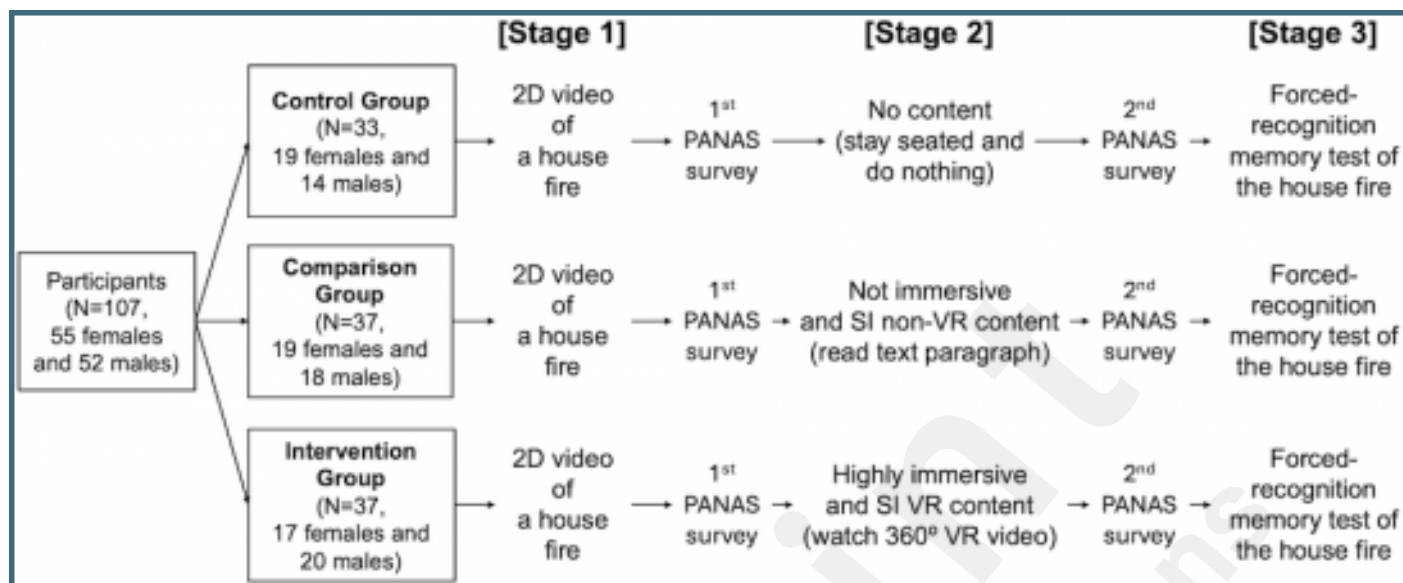
Supplementary Files

Figures

Cognitive model for memory and emotion of traumatic events (adapted from Ehlers & Clark [2000]).



A three-stage experimental procedure.



Snapshots of the 2D video of a real house fire: left-view from the front, right-view from the back.



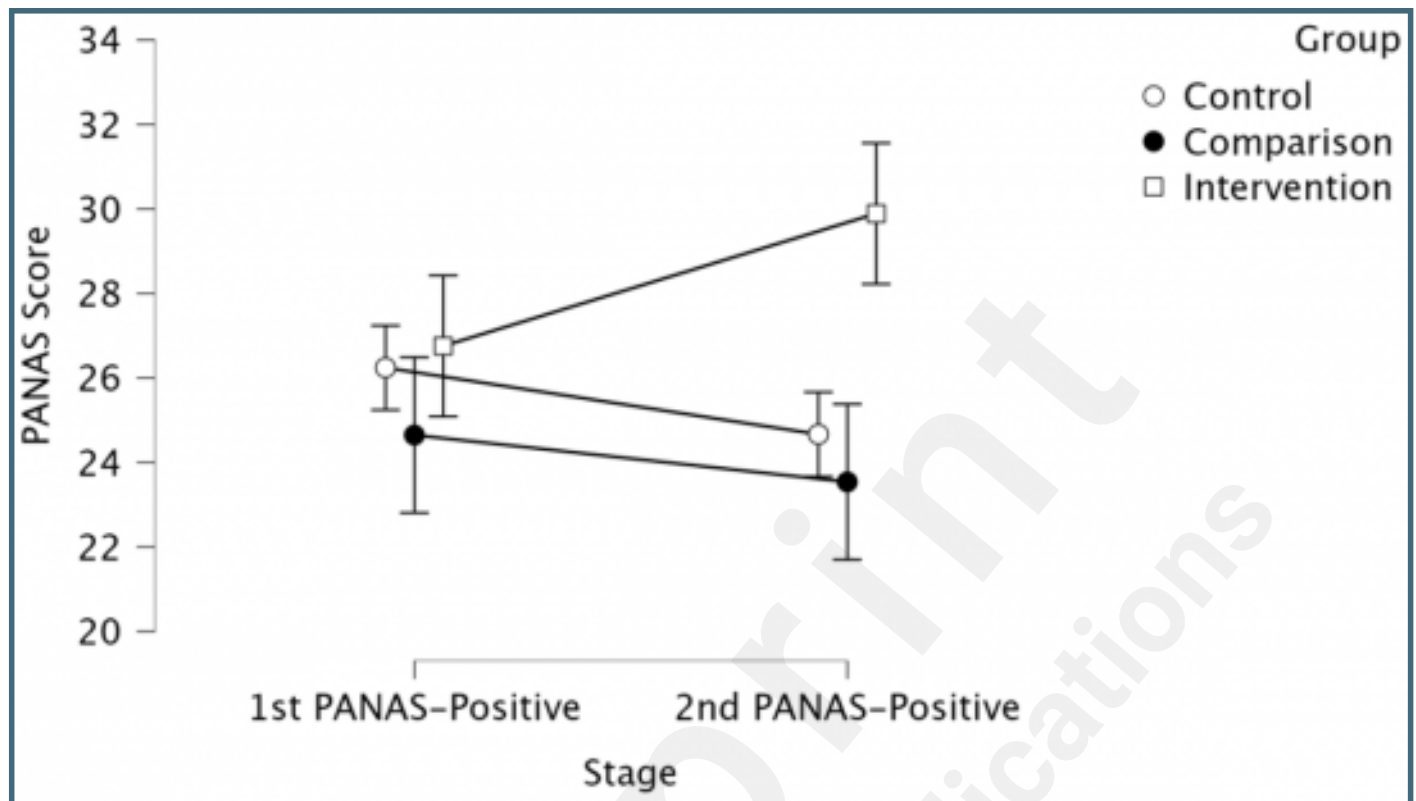
Snapshots of the 360°VR video of the Egyptian Ocean.



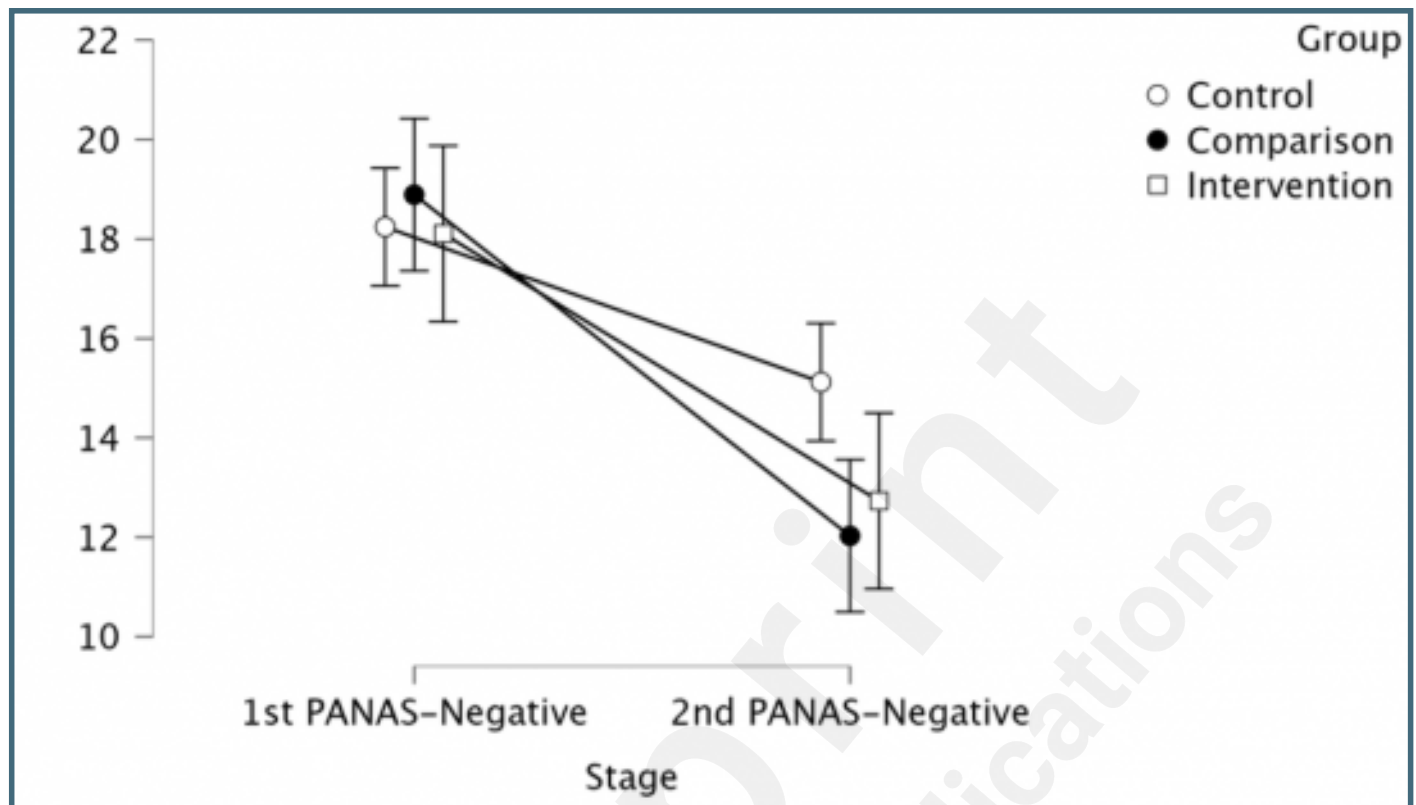
An example of a true image and a fake image of the house fire. The image on the left is a true snapshot image from the fire video and the image on the right is a modified (fake) image using the generative AI software. In the fake image, the fire and the smoke near the house were replaced with another small car that has no fire damage.



Mean positive PANAS scores between groups at the first and second stage with 95% CI.



Mean negative PANAS scores between groups at the first and second stage with 95% CI.



TOC/Feature image for homepages

A female firefighter wearing a VR headset to rest.

