Detection and Prevention of Post-Traumatic Stress Disorder Risk in First Responders by Means of a Virtual Reality Protocol

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Abstract

This presentation reports two VR-based studies examining PTSD-related vulnerability in first responders. Study 1 assessed physiological responses in 84 firefighters, showing that probable PTSD was associated with lower baseline heart rate variability, suggesting reduced autonomic flexibility at rest. Study 2 examined decision-making in 368 first responders and found that probable PTSD predicted poorer performance in emergency scenarios. Across studies, VR distinguished physiological and behavioral markers of vulnerability in ecologically relevant contexts. The findings support VR as a promising tool for PTSD detection and prevention.

1. Introduction

First responders are routinely confronted with potentially traumatic events, including sudden death, severe injuries, threats to personal safety, and repeated exposure to human suffering. This occupational exposure places firefighters, ambulance personnel, paramedics, and other emergency professionals at increased risk for post-traumatic stress disorder (PTSD), with prevalence estimates generally exceeding those reported for the general population (António et al., 2025; Berger et al., 2012; Petrie et al., 2018). Beyond symptom burden, PTSD may also affect capacities that are central to emergency work, including autonomic regulation, attention, processing speed, and emergency decision-making.

Virtual reality (VR) offers a methodologically and ethically useful way to assess these processes. It allows researchers to recreate high-pressure emergency contexts in a standardized, repeatable, and controlled environment, without exposing first responders or victims to real-world danger. For this reason, VR has been increasingly used in training and stress induction research (Dammen et al., 2022; Heldring et al., 2024).

However, its potential as a combined detection and prevention tool for PTSD-related vulnerability in first responders remains underdeveloped. The present extended abstract integrates two complementary VR-based studies to examine whether immersive emergency simulations can identify

physiological and decision-making markers of PTSD-related vulnerability in first responders, with implications for early detection and prevention.

2. Virtual reality protocol and study overview

Both studies used immersive medical emergency scenarios designed to approximate operationally relevant situations for first responders. The VR protocol included avatar-based emergency scenes with audiovisual cues, time pressure, and decision points based on professional emergency-response procedures. Scenarios included, for example, a road-traffic accident involving injured victims and a pediatric cardiorespiratory arrest. The scenarios were developed from previous qualitative work with first responders and refined with professional input to increase ecological validity and procedural relevance.

Study 1 (António et al., 2025a) focused on physiological vulnerability. Eighty-four firefighters completed the PTSD Checklist for DSM-5 (PCL-5) and took part in a VR exposure while physiological data were recorded.

Heart rate variability (HRV), indexed by the standard deviation of NN intervals (SDNN), was used as a marker of autonomic flexibility, whereas skin conductance level (SCL) was used as an indicator of sympathetic arousal. Physiological data were collected during a one-minute baseline and during VR exposure.

Study 2 (Pinto et al., 2024) focused on behavioral performance during emergency decision-making. The sample included 368 Portuguese first responders. Participants completed measures of traumatic exposure and PTSD symptoms and were then exposed to two VR emergency scenarios. The task recorded the number of incorrect decisions and the time required to select the correct response. A composite emergency decision-making score was used, combining decision accuracy and reaction time, so that poorer performance reflected slower and/or less accurate decision-making.

Study	Sample	Primary markers	Main contribution
1	84 firefighters	Baseline/task HRV and SCL	Lower baseline HRV in probable PTSD, suggesting reduced autonomic flexibility at rest.
2	368 first responders	VR errors and reaction time	Probable PTSD predicted poorer emergency decision-making in immersive scenarios.

Table 1: Integrated overview of the two virtual reality studies.

3. Findings

In Study 1, first responders with probable PTSD showed significantly lower HRV at baseline. Using the PCL-5 cutoff score of 31, participants without probable PTSD had higher baseline SDNN than those with probable PTSD (M = 72.39 vs. 40.63 ms), with a medium effect size. The same pattern was obtained when probable PTSD was classified according to DSM-5 cluster criteria (M = 70.37 vs. 35.62 ms), with a large effect size. These findings suggest lower parasympathetic mod-

ulation and reduced autonomic flexibility at rest among first responders with probable PTSD, consistent with evidence linking PTSD to autonomic dysregulation and lower HRV (Schneider and Schwerdtfeger, 2020; Shaffer and Ginsberg, 2017).

However, HRV did not significantly differentiate probable PTSD groups during the VR task, and SCL did not significantly differentiate groups at baseline or during VR exposure. This pattern suggests that resting autonomic regulation may be more sensitive to PTSD-related vulnerability than task-phase HRV in this specific protocol. It also indicates that SCL measurement in active VR settings may be vulnerable to artifacts associated with movement, electrode displacement, or contextual factors such as temperature. Therefore, the physiological findings support HRV as a promising marker, while also indicating the need for longer baselines, recovery phases, larger samples, and improved SCL acquisition procedures.

In Study 2, 85 first responders (23.10%) met DSM-5 criteria for probable PTSD. Those with probable PTSD showed poorer emergency decision-making than those without probable PTSD, even after adjusting for age, years of education, and years of job experience. Specifically, they had higher composite decision-making scores, indicating slower and/or less accurate performance in the VR scenarios ($M = 19.60$ vs. 17.87; $F(1, 360) = 5.32$, $p = .02$, partial eta squared = .015). Structural equation modelling further showed that traumatic events had a direct negative association with decision-making scores, suggesting that greater professional exposure was associated with faster and more accurate decisions. However, traumatic exposure also had an indirect positive effect through PTSD symptoms, indicating that when exposure is accompanied by PTSD symptoms, performance becomes slower and less accurate.

Taken together, the two studies suggest that VR can reveal complementary markers of PTSD-related vulnerability. Study 1 identified a physiological marker at rest, whereas Study 2 identified a behavioral marker during simulated emergency response. Importantly, the behavioral data distinguish between exposure as professional experience, which may improve emergency performance, and PTSD symptoms as a vulnerability pathway, which may undermine decision-making under pressure.

4. Implications for detection and prevention

These findings have practical implications for the use of VR in trauma-informed occupational health for first responders. First, VR protocols may complement traditional self-report screening by providing performance-based and physiological information in controlled, ecologically relevant contexts. A screening model that integrates PCL-5 scores, resting HRV, and VR decision-making could help identify first responders who show early signs of vulnerability before difficulties become evident during real emergencies. Such use should not be interpreted as a clinical diagnosis, but as a risk-detection and referral-support tool.

Second, the protocol has prevention potential. Repeated VR assessments could be used to monitor change over time, evaluate readiness to return to duty after high-impact events, and identify professionals who may benefit from targeted psychological support, resilience training, or trauma-focused intervention. Because the protocol uses standardized emergency scenarios, it could also support stress-inoculation and decision-making training while allowing objective monitoring of errors, response times, and physiological regulation.

Third, the findings support organizational prevention strategies. First responder organizations should move beyond purely individual models of PTSD risk and adopt trauma-informed systems that combine routine screening, confidential referral pathways, supervisor education, and training designed to preserve operational performance under stress. VR is particularly aligned with this goal because it allows realistic but safe exposure to high-pressure scenarios, while generating data that can inform both individual support and organizational policy.

5. Conclusions

Across two studies, immersive VR differentiated markers of PTSD-related vulnerability in first responders. Probable PTSD was associated with lower baseline HRV, suggesting reduced autonomic flexibility at rest, and with poorer decision-making in emergency scenarios, suggesting potential operational consequences. These findings position VR not only as a training technology, but also as a promising platform for risk detection, prevention, and trauma-informed support in first responder populations. Future work should include longitudinal designs, clinical interviews, recovery-phase physiological data, and validation of integrated physiological-behavioral risk profiles.

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