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A Flame in the Game: a quasi-experimental study exploring immersive multimodal Virtual Reality (VR) training, affective states and ecological validity in healthy firefighters

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Submitted to: JMIR Serious Games
on: October 15, 2023

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A Flame in the Game: a quasi-experimental study exploring immersive multimodal Virtual Reality (VR) training, affective states and ecological validity in healthy firefighters

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Abstract

Background: Firefighters face stressful life-threatening events on a daily basis, requiring fast decision-making. To better prepare for those situations, training in realistic settings is paramount, but it can be harmful for the firefighters since errors can lead to harm or even death. Virtual Reality (VR) simulations provide the desired realism while enabling practice in a secure and controlled manner. Firefighters' affective states are also crucial because this group is at higher risk among emergency workers.

Objective: To assess the impact of simulated experiences in a sample of firefighters, this study pursues a multivariate approach, comprising cognitive performance, situational awareness, depression, anxiety, stress, adversity, post-traumatic stress disorder (PTSD) severity, and affective states. The efficacy of an innovative VR haptic system, exploring its impact on firefighter performance was also tested.

Methods: In collaboration with the Portuguese National Fire Service School, 22 firefighters were submitted to two distinct immersive scenarios using the FLAIM Trainer VR system (a neutral and an arousing scenario), while recording physiological data. Baseline cognitive performance, depression, anxiety, and stress, adverse events as a firefighter and PTSD symptoms were evaluated. Positive and negative affective states were measured before, between and after each scenario. Situational awareness, sense of presence, ecological validity, engagement and negative effects resulting from VR immersion experience were tested.

Results: Baseline positive affect was high (mean 32.4, SD 7.2) and increased after the VR tasks (Partial ?2=0.52, Greenhouse-Geisser F1.82,32.78=19.73, P<.001). Contrarily, mean negative affect remained low (range 11.0-11.9) throughout the study (Partial ?2=0.02, Greenhouse-Geisser F2.13,38.4=0.39, P=.69). Participants' feedback on the VR sense of presence was also positive, reporting high sense of physical space (mean 3.9, SD 0.8), ecological validity (mean 3.8, SD 0.6) and engagement (mean 3.8, SD 0.6). Engagement was related to the number of adverse events previously experienced (r=0.49, P=.02) and to positive affect (after all VR tasks) (r=0.55, P=.02). Conversely, participants reported few negative effects (mean 1.6, SD 0.5). They correlated positively with negative affect (after all VR tasks) (r=0.58, P=.01) and with avoidance (r=0.70, P=.002), a PTSD symptom. Performance related to situational awareness was positive (mean 46.4, SD 34.5), although no relation was found to metacognitively perceived situational awareness (r=-0.12, P=.59).

Conclusions: This study demonstrated that VR is an effective alternative to in-person training, as it was considered ecologically valid, engaging, and promoted positive emotions, with few negative repercussions. It further demonstrated how a VR setting can be used to test firefighters' performance and their awareness of a situation. Further research is needed, namely to guarantee that firefighters with PTSD symptomatology are not negatively affected by VR. This study strengthened the evidence in favor of VR

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training and provides new insights on the emotional and cognitive impact it has on the trainee.

(JMIR Preprints 15/10/2023:53683)
DOI: https://doi.org/10.2196/preprints.53683

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A Flame in the Game: a quasi-experimental study exploring immersive multimodal Virtual Reality (VR) training, affective states and ecological validity in healthy firefighters

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Abstract

Background: Firefighters face stressful life-threatening events on a daily basis, requiring fast decision-making. To better prepare for those situations, training in realistic settings is paramount, but it can be harmful for the firefighters since errors can lead to harm or even death. Virtual Reality (VR) simulations provide the desired realism while enabling practice in a secure and controlled manner. Firefighters' affective states are also crucial as a higher risk group among emergency workers.

Objective: To assess the impact on affective states of two simulated immersive experiences in a sample of healthy firefighters (before, during and after the simulation), we pursued a multivariate approach, comprising cognitive performance, situational awareness, depression, anxiety, stress, adversity, post-traumatic stress disorder (PTSD) severity, and emotions. The efficacy and ecological validity of an innovative VR haptic system, exploring its impact on performance was also tested.

Methods: In collaboration with the Portuguese National Fire Service School, 22 healthy firefighters were submitted to two immersive scenarios using the FLAIM Trainer VR system (neutral and arousing scenarios), while recording physiological data, in a quasi-experimental study. Baseline cognitive performance, depression, anxiety, and stress, adverse events and severity of PTSD symptoms were evaluated. Positive and negative affective states were measured before, between and after each scenario. Situational awareness, sense of presence, ecological validity, engagement and negative effects resulting from VR immersion experience were tested.

Results: Baseline positive affect was high (mean 32.4, SD 7.2) and increased after the VR tasks (*Partial* η^2=0.52, *Greenhouse-Geisser* $F_{1.82,32.78}$=19.73, P<.001). Contrarily, mean negative affect remained low (range 11.0-11.9) throughout the study (*Partial* η^2=0.02, *Greenhouse-Geisser* $F_{2.13,38.4}$=0.39, P=.69). Participants' feedback on the VR sense of presence was also positive, reporting high sense of physical space (mean 3.9, SD 0.8), ecological validity (mean 3.8, SD 0.6) and engagement (mean 3.8, SD 0.6). Engagement was related to the number of previously experienced adverse events (r=0.49, P=.02) and to positive affect (after the last VR task) (r=0.55, P=.02). Conversely, participants reported few negative effects (mean 1.6, SD 0.5). They correlated positively with negative affect (after the last VR task) (r=0.58, P=.01) and with avoidance (r=0.70, P=.002), a PTSD symptom. Performance related to situational awareness was positive (mean 46.4, SD 34.5), although no relation was found to metacognitively perceived situational awareness (r=-0.12, P=.59).

Conclusions: This study demonstrated that VR is an effective alternative to in-person training, as it was considered ecologically valid, engaging, and promoted positive emotions, with few negative repercussions. This corroborates the use of a VR setting to test firefighters' performance and situational awareness. Further research is needed, to ascertain that firefighters with PTSD symptomatology are not negatively affected by VR. This study favors the use of VR training and provides new insights on the emotional and cognitive impact it has on the trainee.

Keywords: Virtual Reality; Firefighter; Training; PTSD; Emotion; Situational awareness; Engagement; Ecological validity; Multivariate approach.

Introduction

Over the last few years, gamification and serious games applied to non-game settings have been becoming a visible theme, promoting knowledge acquisition, users' engagement and strategic skills [1]. More precisely, Virtual Reality (VR) serious games training systems have been showing high potential for many purposes, namely in the professional instruction field ([2,3]). Simulated situations under high stress levels have been gaining greater interest for some time. As an example, Keitel and colleagues [4] examined endocrine and psychological stress responses in medical students during two simulated stress scenarios (a stress situation induced at a laboratory and a simulated emergency situation) compared to a rest condition.

For firefighter workers this assumes special importance related to the idiosyncrasies of strenuous everyday duties [2]. Their functions require a repetitive and continuous preparation, to acquire and preserve skills and refresh expertise, which can be potentially facilitated through VR tools. These systems present direct advantages compared to traditional in-person training, as a cost-effective and safer realistic alternative to perform dangerous or complex tasks, train decision-making and related abilities in secure environments, replicating similar conditions to real life, with less time and **minor** consumption of resources, or other constraints.

Furthermore, VR applications make available a plurality of training scenarios with high ecological validity [2]. Ecological validity can be defined as "the ability to generalize experimental results to different populations, situations, and variables" (see [5]) (*p*.486) , and is related to the cues contained in an experiment that permit the generalization from the laboratory to real life. VR settings have been successfully used to increase the ecological validity of several experiments [6], as well as enhance participants daily activities, be it rehabilitation for the elderly [7], improving cognitive function of children with ADHD [8], or simply shopping in a virtual supermarket [9]

The high ecological validity of VR scenarios allows for customized realistic immersive scenarios fitted to the training purpose [10] without putting the workers' lives or properties in danger [11]. These systems present several other advantages, namely the importance of being an observer

[12], repeated practice, promoting the users' engagement and motivation towards the training tasks, and consequently, the retention of competencies and transference of knowledge [2,13]. VR experiences also encourage post-training session discussions and member collaboration [14]. This is critical because coordination and cooperation are essential between firefighters. Furthermore, VR technology provides user insight into simulated experiences, gains into real-life contexts, and can be applied for a high range of personnel categories (eg, trainees, commanders).

As presented by Narciso and colleagues [15], the ideal VR training system should reproduce with the best accuracy possible the real-world situations, such that the user can be immersed in the virtual environment and perceive it as close to reality. Thus, the effectiveness of the VR system and its ability to mobilize the user are crucial points to have in account regarding firefighting training. Moreover, these workers have to manage critical and dangerous incidents, operate in intense and stressful unpredictable conditions, face hazardous scenarios, deal with human suffering, and handle one's own and colleagues' emotions.

In the last years, some studies have been applying simulated tasks (eg, [16]) and VR systems with several devices and tools (eg, game engines using 3D, software, VR equipment) for the purpose of firefighter instruction (eg, [[10,13,17–22]]). Reis and Neves [23,24] presented a list of guidelines for simulation in training contexts using VR tools, namely physical and psychological fidelity, interaction, immersive features and realism. Also, Saghafian and colleagues [25] highlighted the importance of realism to increase acceptance level of the users, effectiveness and transfer of knowledge, as well the role of emotions in VR contexts, for example when using a VR fire extinguisher training tool for critical industries.

In our setting, developments have been made in this area, with studies focused on VR for firefighting training purposes (eg, [15,23,26–28]). In a specific study by Narciso and colleagues [29] virtual environments were used to investigate the effects of multisensory – audiovisual, and audiovisual combined with smell/ heat/ weight/ uniform/ mask/ combined - stimuli on stress (using heart rate and self-report measures), fatigue, cybersickness, presence and knowledge transfer. This study was conducted in the context of firefighter training and involved a sample of 91 individuals who were not firefighters. Another pilot study revealed the positive effects of resorting to VR tasks for firefighter training purposes, namely in decision-making abilities during emergency actions [24].

Notwithstanding the existing literature, a clear gap remains in this area, including studies using multimodal experiments capable of integrating realistic immersive scenarios, neuropsychological measures and biological parameters. The study of Andrews [16] raised attention to ecological and content validity issues of simulated emergency tasks for firefighters, aggregating findings from 60 protocols. The author also highlighted the lack of empirical studies concerning simulating tasks. Indeed, there is a clear need for in-depth ecological experiences and VR systems might be a valid solution with high application potential.

Some explicit intents have been made to increase realism in firefighter training (eg, [15,16,30]). For example, the study of Butler and colleagues [30] has sought to integrate a multicomponent method, including behavioral and biological parameters in a sample of incident commanders to investigate standard operating procedures and decision-making during simulated events. However, the technology used was scarcely immersive (the study used moving images and did not resort to VR technology). Also, another study [31] investigated decision-making in a sample of Portuguese trainees who became certified for the job, using a realistic VR system coupled to a haptic thermal device. The impact of VR was analyzed, but neither physiological measures, nor the emotional and neuropsychological components were included.

Other studies addressed the firefighters' situational awareness (eg, [12,32–34]), comprehended as the "knowledge or how well the individual discriminates true (signal) from false (noise) information" [32] (*p.* 139). However, the literature seems still scarce in studying widely the potential of including this variable applied to firefighter training in a broader perspective, as argued by Chiu, namely combined with VR methodology [12].

In spite of the aforementioned body of work, further research is still needed regarding the effectiveness of VR training applied to firefighter instruction. For example, recently, in their study Narciso and colleagues [35] applied a heart rate variability measure and self-reported questionnaires to a sample of Portuguese firefighters in this VR context. Although the authors found promising results related to stress, sense of presence, cybersickness, and transference **of** knowledge, the real environment training demonstrated superior results compared to the VR setting. This is unsurprising and does not preclude the use VR in transfer situation in which learning in real settings is not practicable.

To successfully perform their duties, firefighters need flexibility for diverse tasks and operations, have to act immediately, make critical decisions in adverse conditions, deal with fatigue, and control their emotions. After interventions, it is central for their mental health to return to a homeostatically appropriate state to carry on their lives. In this regard, a systematic review [36] found some mental health issues within firefighter groups, namely post-traumatic stress disorder (PTSD), anxiety and depression. Oliveira and colleagues [37] also investigated this question and replicated these findings.

Emotions play a crucial role in the mental health of firefighters [38]. Findings from Godfrey

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and colleagues [39] revealed that difficulties in emotion regulation mechanisms were positively associated with the severity of PTSD symptomatology in a sample of firefighters, and might be a valuable target considering the vulnerability of this population. Stanley and colleagues [40] highlighted greater levels of distress tolerance as a key trait for firefighting service, considered as a capability to deal with negative emotional and physical states. Specifically, the fire service is an emotionally challenging work, being cognitively demanding and physically overloading, with implications on the decision-making process [41]. In this regard, Robinson and colleagues [42] found some impairments in cognitive functions among non-firefighter participants (namely in visual declarative memory and working memory domains, immediately after the exposure and 20 minutes after) to the threat during a simulated firefighting emergency. Furthermore, a study found that shift-workers have a higher propensity to show cognitive impairment due to sleep deprivation [43].

This state might affect fundamental cognitive abilities, crucial to guarantee the success, effectiveness and safety of the operations. Previous research indicated that firefighter tasks require higher cognitive function during their hazardous activities [44,45]. Some examples of these higher order cognition are attention (as a broad construct) - the ability to maintain the focus over the time; vigilance - the capacity to maintain continuous attention to specific stimuli, helping in information discrimination; processing speed - the ability to acquire and process information rapidly, and consequently execute [46]; analytical thinking - the ability to solve problems in virtue of understanding logical principles, assessing the evidence [47]; accurate decision making ability, as a complex process include making difficult choices, weighting potential risks and rewards, taking actions and analyzing the effects [48,49]; working memory - the capacity to maintain information accessible while performing other complex tasks [50], involving temporary storage and manipulation of information; cognitive flexibility - the ability to respond in a readily way, changing selectively according to the environment's demands [51]; and awareness of the situation - the ability to extract continuously information from the dynamic environment around [52], among other executive functions.

Considering the state of art, the present study used an Australian VR realistic training system, the FLAIM Trainer, which uses immersive technology for firefighter training and learning. This simulator comprises several cutting-edge characteristics, including various immersive virtual fire scenarios, using a multi-sensory interface with several customized and haptic components (eg, heat suit, hose-line and a nozzle). For the purpose of this work, a multimodal approach was implemented, using realistic training tasks, combined with psychological and physiological measures, including evaluation of executive functions, and firefighters' performance regarding situational awareness.

The main goal of this work was to assess the impact on positive and negative emotions in a sample of Portuguese healthy firefighters, of two simulated experiences, pursuing a multivariate approach, and ultimately investigate affective aspects of the immersive performance in these two virtual environments: i) a neutral scenario (exploration of the surrounding area of a rural residence, including preventive tasks) and ii) an arousing stressful scenario (extinction of a residential fire, including victims' rescue actions). The relation between cognitive performance, reported levels of anxiety, depression, stress, PTSD severity, adverse events witnessed as a firefighter prior to the experiment, and affective states before, during, and after the VR task were also analyzed. Another aim is linked with the latter question and concerns with evaluation of an innovative and haptic VR system's (the FLAIM Trainer) impact on firefighter training and daily duties. The ecological effectiveness and the direct and indirect effects of these immersive scenarios was tested, including evaluation of firefighters' situational awareness fitted to firefighter demands. These aspects have direct implications for firefighting work and performance in relation to firefighter training and the role of emotion regulation mechanisms in daily-life duties of these workers.

Methods

The sample was composed by 22 healthy firefighters from several fire stations in Portugal (17/22, 77% from Lisbon and Tagus Valley area), recruited in collaboration with the Portuguese National Fire Service School at Sintra (Portugal). The exclusion criteria were the presence of a severe psychiatric or physical condition affecting brain and behavior, including PTSD, drug or alcohol addiction, significant vision and hearing problems, pharmacological treatment with effects on brain mechanisms, and never having participated in firefighting campaigns. For detailed description of the sample, see Results.

Protocol Procedure

Participants provided written informed consent. The study was approved by the local Research Ethics Committee of the Faculty of Medicine of the University of Coimbra and was guided by the Declaration of Helsinki of 1975 and its latest updates. All data were handled under rigorous protective measures in place to safeguard participant information, specifically an alphanumeric code was attributed to all participants following a de-identified process in order to preserve participants' confidentiality and privacy. No compensation was provided for participation in the study. The experiment was conducted at the Portuguese National Fire Service School facilities at Sintra (Portugal), except for two participants who performed the tasks at the Institute for Nuclear Sciences

Applied to Health (ICNAS), University of Coimbra (Portugal), with a quasi-experimental study design. Data collection at the Portuguese National Fire Service School occurred during day-time, with participants who were at the school attending a course or called upon from close-by corporations to participate. Data was also collected during day-time at ICNAS, with two firefighters who purposely went to the Institute to participate in the study on a day off from work. Collection at both places during the participants time-off work. All participants underwent an individual session, including a comprehensive semi-structured interview regarding sociodemographic information and self-reported medical history, followed by psychological assessment, comprised of self-report measures and a battery of computerized tests to assess cognitive function. The total duration of the psychological assessment session was around one hour. Then, each participant was conducted to a separate room to take part in the virtual experience session, including measurement of biosignals, and filling of self-report questionnaires immediately after performing in each experimental scenario, to evaluate their experience in the VR environment at various moments in time (Figure 1).

It was determined that the participants should complete the psychological assessment first and the VR experience afterwards, due to the consideration that performing the VR task first could elicit a particularly positive or negative mood, and thus lead to mood-congruent memory recall bias [53,54] and inaccurate reports during the posterior psychological assessment. To prevent the opposite effect of the impact of the psychological assessment on the VR task performance, it was ensured the participants had at least 25 minutes to rest between the psychological assessment and the VR task.

During all VR experiments (including during the filling of self-report measures) firefighters wore urban-standard fire combat equipment, comprising protective clothing and boots to accurately simulate a real situation.

Outcome Measures

Sociodemographic and self reported medical data. A semi-structured interview was conducted to collect sociodemographic data, information regarding firefighter activity and medical history.

PANAS - The Positive and Negative Affect Schedule (Portuguese version: [55]; original: [56]

The scale measures 20 emotions, comprising two dimensions - Positive Affect (PA) and Negative Affect (NA). The firefighters had to classify how they felt “at the present moment”, using a scale between 1 (“very slightly or not at all”) and 5 (“very much”), providing information about the participant’s affective state exactly at the time of reporting (“right now”). This temporal instruction was foreseen by the original authors [56] . According to them, PA contemplates the degree in which a person feels “enthusiastic, active, and alert” (*p.* 1063). Conversely, NA reflects unpleasant moods as “anger, contempt, disgust, guilt, fear, and nervousness” (*p.* 1063). The score is calculated separately for the PA and NA scales, ranging between 10 and 50. Higher scores indicate higher levels of positive and negative affect at the moment of responding. The PANAS scale was administered before the VR experience (T0 - baseline) and immediately after performing each scenario, in order to measure the mood induced by the experience. Three participants did not perform the last VR setting (second control condition) and therefore did not complete the last PANAS.

DASS-21 – Depression Anxiety Stress Scales- 21 items (Portuguese version: [57]; original: [58])
DASS-21 is a self-reported measure with 21-item assessing anxiety, depression and stress during the last week, using a four-point Likert scale (0 -“did not apply to me at all” to 3-“applied to me very much or most of the time”). The scores range from 0 to 21, with higher scores indicate higher emotional levels [57]. In this study, we followed the cut-off scores for conventional severity labels recommended by the authors [59]. Nevertheless, for more details, the manual should be consulted, to avoid misinterpretation, as recommended by the authors.
This measure was completed before the VR experiment.

QEPAT – (in Portuguese: Questionário de Exposição e Perturbação dos Acontecimentos Traumáticos, a Portuguese questionnaire related to the exposure and disturbance of traumatic events) (updated version of this instrument by A. Maia, C. Carvalho, and R. Lopes in 2016; original Portuguese version with 40 items: [60]:
A self-report questionnaire related to the exposure and disturbance of traumatic events with a list of 42 adverse events (with possibility to add another event, non-specified previously) directed at firefighting work. For each event, the firefighter should indicate the level of exposure during firefighting service, using a five-point Likert scale (0-“never” to 4-“frequently”) and the level of subjective disturbance caused by the event, using a similar five-point scale (0-“not at all” to 4-“very much”). In this study, all participants were instructed to classify the event’s impact only for the situations witnessed at least once. Additionally, firefighters were asked to select the most impactful event, indicating additional information about the experience, including the level of perceived trauma.

PCL-5 – PTSD Checklist for DSM-5 (Portuguese version by R. Ferreira, L. Ribeiro, P. Santos, and A.

Maia 2016 [61]; original: [62]):

A self-report 20-item scale to evaluate the severity of PTSD-related symptoms, used here to exclude firefighters with suspicion of PTSD, for screening purposes. This scale also allows the assessment of PTSD clusters, according to the Diagnostic and Statistical Manual of Mental Disorders – Fifth edition (DSM-5) [63]: Intrusion, Avoidance, Negative Alterations in Cognition and Mood (NACM), and Alterations in Arousal and Reactivity (AAR).

Participants completed the PCL-5 immediately after the QEPAT, and rated the frequency of each symptom, during the last month, using a five-point Likert scale (0-"not at all" to 4-"extremely"), regarding the most impactful event experience as a firefighter, selected previous in the QEPAT, in an attempt to define a traumatic event criterion restricted to firefighter duties, given the aim of the study (both scales were completed before the VR experience), and ultimately, analyze the presence or absence of PTSD symptoms and their severity, in order to guarantee the participants' security and remove them from any potential triggering situations.

The scale ranges from 0 to 80, with higher scores expressing higher symptoms' severity. In this study, the 31 cut-off was used to evaluate the probable presence of PTSD [64]. According to the authors, the scale also allows to define a provisional diagnosis of PTSD, considering items reported as "moderately" or higher (at least one symptom reported from Intrusion and Avoidance dimensions, and two or more symptoms from cluster NACM and AAR).

CANTAB – Cambridge Neuropsychological Test Automated Battery [65]:

Four tests were selected from this computerized cognitive test battery to assess the cognitive performance on a variety of specific cognitive abilities and obtain outputs of relevant skills to firefighting (ie, discrimination of significant stimuli, visual attention and flexibility, visuospatial memory, sustained attention, and executive functions) in order to characterize this sample of healthy firefighters, and to ascertain cognitive functioning.

Two different metrics were used across the four tests: the *z* scores (with a normative mean of 0) and percentile ranks (considering data collected through a web-based cognitive assessment application from a normative sample, available from CANTAB software, by gender, level of education and date of birth; comparison was made against all three demographics). Various tests from this digital cognitive battery have been widely used in research, for example to study cognitive functions of firefighters under hot conditions [44]) or military troops [66], as well as executive functions [67] and sustained attention in the presence of PTSD symptoms [68].

The selected tests were administered in this sequence, before VR tasks:

MOT - Motor Screening Task (MOT), comprises a set of stimuli (10 colored crosses) as a screening measure for sensorimotor deficits or comprehension difficulties, in which firefighters had to tap the target on the screen, quickly and accurately during the trials.

SWM - Spatial Working Memory (extended version), as a measure of executive functioning, specifically visuospatial working memory, ability to retain and manipulate information previously visualized, which addresses lobe frontal functioning [69]. The tests provide a comprehension over the strategy adopted by the firefighters during the trials, as difficulty (number of squares) increases progressively and the participant must select the boxes to find the "token" inside and then transport them to an empty column. An elimination and memorization strategy are required since the instruction given is to not select the same token twice. In this study, the output measures used for this test (labeled as SWMBE468) was the number of errors provided by revisiting a square where a yellow token has been found in a previous search, across all 4, 6, and 8 trials [65].

RVP – Rapid Visual Information Processing (3 targets version)

This task is a measure of sustained attention and consists of three target sequences, which appear randomized on the screen mixed with digits from 2 to 9. This type of task is based on the principles of Signal Detection Theory and decision-making process [68]. Participants must tap the screen quickly when a sequence appears and not tap with other digits. The level of difficulty progressively increases from one to three sequences consecutively. In this study, two metrics were considered: RVPA, as a measure of accuracy to detect correctly the targets ("the true positives"); and RVPPFA, representing the probability of false alarm, as a measure of quality - a proportion which combines the number of times the participant provided correct responses (ie, not tapping the screen when the target sequence is not shown) and incorrect responses (ie, inappropriately choosing to tap the screen when the target sequence is not shown) [65].

IED - Intra-Extra Dimensional Set Shift (Lines First Repeated version)

This test is similar to the Wisconsin Card Sorting Test (WCST, [70]) and measures executive functioning, and more specifically problem-solving ability, trial-error learning, planning, and cognitive flexibility. The test starts with a correct pattern and the participant has to learn the underlying rule to discover the correct response, using the feedback words ("correct" or "incorrect"). The level of difficulty progressively increases, from simpler to more complex stimuli. The measure used in this study was: the Total Errors Adjusted (IEDYERTA) - selecting a stimulus incorrectly, which does not follow the current rule, adjusted for every stage that was not completed. It represents a measure of efficiency in the test [65]

QASA – Quantitative Analysis of Situation Awareness (instrument created for this study following the methodology proposed by Edgar and colleagues [71]):

This version of the QASA instrument was developed specifically for this study, as it assesses the participants' awareness of a given situation. It is especially useful in open-world simulated firefighting training situations, such as the one used in the present study, seeing how it provides a measure of performance of the firefighters' attention to the VR task, which is a distinguishing aspect of being involved in the arduous firefighters' duties.

This test is composed of two types of scales. The first consists of statements regarding the simulation (only for the EC condition, the arousing scenario), seven of which are true and the other seven are false. The participants had to indicate if they believed the statement to be true or false. The second type was a confidence scale, on which the participants were required to indicate, on a four-point Likert scale (1 to 4), how confident they were on their previous answers concerning the truthiness of the statements.

Given the exploratory open-world nature of the simulated task, special attention was given during construction of the test to include only statements that addressed elements of the simulation that the participant was sure to see. The final test was constructed according to the following procedure: an item matrix and item pool were created; the items which were clearer in their interpretation were selected; an interview with an experienced firefighter was conducted to ensure the adequacy of the items, with adjustments made accordingly; two pilot healthy firefighters conducted the simulation VR task, allowing for betterment of the items; the resulting final version was the one used in the study.

This instrument evaluates actual situational awareness (measured by A'), bias of information acceptance or rejection (measured by B''), and perceived situational awareness (PSA), following a signal detection theory approach [72]. It is used here as a measure of actual performance regarding the participants' situational attention awareness, and their ability to detect and recall which elements were present in the simulation, and which were not (ie, the ability to distinguish signal from noise, measured by A'). The test also measures perceived performance (ie, participants' level of confidence in the accuracy of the recall, measured by PSA). Furthermore, it is possible to assess the participants' biases regarding the acceptance or rejection of information (measured by B'', regardless of it being true (ie, signal) or false (ie, noise)). That is, if the participants have a tendency to accept all information as true, even when it is false, or to reject information as false, even when it is true.

As stated by the original authors [71] , A’ and B’’ follow the equations described by Stanislaw and Todorov [72], as seen below in (1) and (2), respectively. A’ ranges from 0 to 1, with 0.5 indicating an inability to distinguish signal (ie, the target, correct responses) from noise (ie, the distractors, wrong responses). Following (2), B’’ ranges from -1 to +1, with negative scores indicating a tendency to accept information as true, even if false (increasing acceptance as values approach -1), and positive scores indicating the opposite, a tendency to reject information as false, even if true (increasing rejection/non-acceptance as values approach 1). A B’’ value of 0 indicates the absence of bias. PSA values are obtained by computing the mean of responses to all confidence items, with higher scores indicating higher confidence in ones’ responses. Following recommendation by the authors [71], all measures were rescaled to a scale ranging from -100 to +100. In the following equations, *H* represents the hit rate (ie, number of “true” statements correctly identified as true, divided by total number of questions) and *F* represents the false alarms (ie, number of “false” statements incorrectly identified as true, divided by the total number of questions).

Equation models to calculate actual situational awareness (A’), and bias of information acceptance or rejection (B’’), following a signal detection theory approach [72].

$$A' = 0.5 + (sign(H-F)\frac{(H-F)^2 + |H-F|}{4\max(H,F) - 4HF} \quad (1)$$

$$B'' = sign(H-F)\frac{H(1-H) - F(1-F)}{H(1-H) + F(1-F)} \quad (2)$$

Note: A’ – Actual situational awareness, B’’ – Bias of information, H – Hit rate, F – False alarms.

ITC-SOPI – ITC-Sense of Presence Inventory (Portuguese version: [73]; original: [74]) (ITC-SOPI i2 media research ltd., 2004; Independent Television Commission, 2000)

The instrument includes 35 items to evaluate the participants’ experience after (two questions) and during (33 questions) the VR simulation, in regard to Sense of Physical Space (the feeling of being physically present into the simulation and measures the ability to control and manipulate details of the experience), Engagement (the level of involvement and interest with the experience), Ecological Validity (measures the realism and naturalness of the VR environment), and Negative Effects (the subjective reactions caused by the simulation) [73]. Participants responded using a five-point Likert scale, with a range between 1-“strongly disagree” to 5-“strongly agree”), where higher scores represent higher levels of sense of presence during the VR experience.

In this study, the ITC-SOPI was the last filled-in measure immediately after the end of the simulation (CC2 moment), but after the PANAS. For participants’ convenience and comfort, they had already removed all equipment at this time. Each dimension produces a mean score. One participant did not complete the ITC-SOPI, given that they discontinued the experiment before completing the last VR scenario (CC2).

Internal consistency of the scales was generally acceptable, although some obtained low Cronbach alpha values. Alpha was lowest for the ITC-SOPI Physical Sense of Space scale (Cronbach α=.32), the PCL-5 Negative Alterations in Cognition and Mood subscale (Cronbach α=.33) and for the Negative Affect PANAS, filled out immediately after the first control condition (CC1) (Cronbach α=.49). Alpha values were more heterogeneous in the subscales of PCL-5, ranging between .33 and .94. Detailed alpha values can be found in Table 1.

Table 1

Characterization of psychological measures’ values

Measures	Mean (SD)	Median (range)	α
DASS-21[a] Depression	1.1 (1.3)	1.0 (0-4)	.50
DASS-21[a] Anxiety	1.2 (1.5)	0.5 (0-5)	.57
DASS-21[a] Stress	3.7 (2.6)	3.5 (0-8)	.68
PCL-5[b] Full Scale	3.9 (4.5)	2.0 (0-12)	.75
PCL-5[b] Intrusion Symptoms	1.0 (1.5)	0.0 (0-5)	.59
PCL-5[b] Avoidance	1.0 (1.9)	0.0 (0-8)	.94
PCL-5[b] NACM[c]	1.1 (1.7)	0.0 (0-6)	.33
PCL-5[b] AAR[d]	0.9 (1.3)	0.0 (0-4)	.56
QEPAT[e] Number of Events	31.9 (4.5)	33.0 (23-40)	-
PANAS[f] T0[g]			
Positive Affect	32.4 (7.2)	33.5 (19-44)	.86
Negative Affect	11.2 (1.6)	11.0 (10-17)	.61
PANAS[f] Control Scenario 1			
Positive Affect	38.0 (7.0)	39.0 (19-50)	.86
Negative Affect	11.0 (1.3)	10.0 (10-14)	.49
PANAS[f] Experimental Scenario			
Positive Affect	40.0 (6.8)	41.0 (17-49)	.85
Negative Affect	11.9 (3.2)	10.0 (10-24)	.81
PANAS[f] Control Scenario 2			
Positive Affect	40.7 (6.6)	43.0 (22-50)	.86

Negative Affect	11.0 (1.8)	10.0 (10-16)	.74
ICT-SOPI[h]			
Sense of Physical Space	3.9 (0.8)	3.8 (2.9-6.4)	.32
Engagement	3.8 (0.6)	3.8 (2.2-4.7)	.68
Ecological Validity	3.8 (0.6)	3.8 (2.8-4.8)	.75
Negative Effects	1.7 (0.6)	1.7 (1.0-3.0)	.76
CANTAB[i]			
SWMBE468[j]	-0.6 (1.3)	-1.0 ((-1.9)-2.3)	-
RVPA[k]	-0.5 (0.6)	-0.5 ((-1.4)-1.2)	-
RVPPFA[l]	0.3 (0.9)	0.1 ((-1.5)-2.3)	-
IEDYERTA[m]	0.0 (0.7)	0.1 ((-1.3)-0.8)	-
QASA[n]			
A'[o]	46.4 (34.5)	45.0 ((-25.0)-92.9)	-
B''[p]	-13.6 (30.3)	0.0 ((-100.0)-9.1)	-
PSA[q]	47.2 (25.0)	47.6 (0-100)	-
Duration of experiment[r]	34.1 (8.6)	33.9 (24.3-47.0)	
Control Condition 1[r]	5.7 (0.5)	5.5 (4.9-7.3)	
Resting interval 1[r]	4.3 (3.3)	3.3 (2.2-17.3)	
Experimental Condition[r]	13.8 (3.8)	13.8 (5.0-20.5)	
Resting interval 2[r]	6.5 (1.6)	5.7 (4.4-8.9)	
Control Condition 2[r]	5.4 (0.2)	5.4 (5.2-5.8)	

[a]Depression Anxiety and Stress Scales – 21 itens; [b]PTSD Checklist for DSM-5; [c]PCL-5 subscale of Negative Alterations in Cognition and Mood; [d]PCL-5 subscale of Alterations in Arousal and Reactivity; [e]Questionnaire related to the exposure and disturbance of traumatic events; [f]Positive and Negative Affect Schedule; [g]Baseline measure; [h]ITC-Sense of Presence Inventory; [i]Cambridge Neuropsychological Test Automated Battery; [j]CANTAB Spatial Working Memory measure; [k]CANTAB Rapid Visual Information Processing, measure of accuracy to detect the targets correctly (*z* scores); [l]CANTAB Rapid Visual Information Processing, measure of the probability of false alarm as quality of performance (*z* scores); [m]CANTAB Intra-Extra Dimensional Set Shift measure (*z* scores); [n]Quantitative Analysis of Situation Awareness; [o]Atual Situational Awareness; [p]Bias of Information Acceptance or Rejection; [q]Perceived Situational Awareness; [r]Duration is presented in minutes

Virtual Reality Session – the setup

The FLAIM Trainer virtual reality training technology was designed for firefighters training and learning, presenting a wide range of simulated fire environments (more than 120 available scenarios in 30 languages) [75], which faithfully reproduce dangerous situations, usually faced in fire duties (eg, highway, national parks, warehouse) or rarer events (eg, fire on a petrol station, engine fire in an aircraft). The system was developed in an attempt to fit the needs of fire duties and integrated professional feedback; instructors can monitor in real-time, review and track trainees' performance. The simulator was acquired for research purposes within firefighters' training.

Some case studies were reported using the FLAIM Trainer VR training system, with positive results [76]. Higher levels of acceptance and usability of this VR system were found among 91 Brazilian military firefighters during a firefighting specialization course [77].

The simulator incorporates feedback and outcomes to assist firefighters in decision-making, along with a proprietary virtual fire behavior technology that mimics real fire. This technology aims to improve high-level skills, such as risk assessment and dynamic thinking, and practical abilities, like muscle memory, radio messaging, hose and nozzle handling) [78]. The hardware was designed **considering** user-friendliness and immersiveness. The user can explore and navigate freely into the scenes facilitated by teleport mode and interact with objects.

The hardware setup includes customized components, namely a self-contained breathing apparatus (SCBA) kit where the virtual reality computer is housed, with a built-in HTC Vive Pro VR headset, a half facemask and lung demand valve to capture respiration and reproduce sounds of breathing, a thermal imaging camera, but also a fire proximity heat suit technology, and a mobile hose-line apparatus with haptic technology, reproducing a realistic jet and nozzle live force; the pump pressure and the suppressant type can be controlled and customized at any time by the instructor. Support equipment including an instructor tablet, HTC VIVE Tracker Puck, charging systems, cables, peripherical hardware, tripods, tracking hardware with base stations (VIVE lighthouses), and VIVE Controller [78,79]. In this experiment, the half facemask, thermal imaging camera and heat suit were not used. Figure 2 demonstrates two firefighters performing the VR tasks.

During VR sessions, biosignals were recorded simultaneously through non-invasive superficial sensors, to study autonomic arousal related to firefighters' emotions and behavior and its impact on decision-making under stressful conditions. The parameters measured were the electrodermal activity (EDA), photoplethysmography (PPG), electrocardiography (ECG), electroencephalography (EEG), and respiration. These data will be reported in a separate study.

The VR experience was divided into three moments, with two different experimental scenarios. The experiment started with a brief tutorial for the user's familiarization of the interaction with the VR system, use of the hose and the teleport mode. Then, the neutral scenario ("Property Emergency Prepare" scenario) (Figure 3) was presented - Control Condition 1 – CC1. The firefighters were instructed to explore the scenario for 5 minutes, to clean the terrain and the nature around a rural property as a prevention and safeguard measure, against potential bushfire risks. In this environment, it was not possible to enter inside the house, but there were several elements outside with which the participant should interact with (eg, cleaning inflammable debris from the nearby zone, ensuring the safety of the animals, preparing the area for a potential fire).

The Experimental Condition (EC) consisted of a residential fire in the first-floor of a house inserted in an urban zone ("Bedroom Fire" scenario) (Figure 4). The scenario ended when the firefighter extinguished the fire and rescued all human victims. The experiment ended with another immersion in the neutral scenario (“Property Emergency Prepare” scenario) (Figure 3) - Control Condition 2 (CC2), for 5 minutes, effectively acting as a post baseline. The firefighters were instructed to act as in a real situation, during all conditions. Three participants did not complete the last scenario (CC2) due to health-related reasons (ie, shortness of breath caused by the physical demands of the EC), technical issues (ie, system crashed due to lack of battery during the task), and because they did not wish to continue participating in the experiment.

Participants took a mean of 34 minutes to complete both control and experimental conditions, also accounting for resting time between the conditions. While a 5-minute time limit was fixed for the control conditions, some participants needed more time to get familiarized with the VR headset and nozzle, so additional time was provided. This additionally had the aim of ensuring the participants were engaged and motivated to perform the experimental condition. The first control condition (CC1) had a mean completion time of 5 minutes and 41 seconds, while the second control condition (CC2) had a mean completion time of 5 minutes and 26 seconds. No time limit was imposed for the experimental condition (EC). Instead, it was determined that the participants had finished the experimental condition once they had completed the two objectives of putting out the fire and saving the victims, or when they themselves decided to terminate the task. Even though participants were encouraged to complete the objectives, they could quit at any time. Only one participant abandoned the experimental condition, after not being able to complete it after 20 minutes and 28 seconds. Furthermore, it was ensured the participants had resting time between conditions to avoid fatigue, although the specific interval duration between conditions was determined by the participants. The mean resting time between CC1 and EC was 4 minutes and 19 seconds, and 6 minutes and 26 seconds between the EC and CC2.

Statistical analysis

Statistical analysis was performed using SPSS version 28 and a significance level of 0.05 was established.

Initially, the normality assumption was tested using Kline’s criteria [80]. All measures were within the expected parameters (ie, skewness lower than |3|, kurtosis lower than |10|) and thus parametric analysis was performed. Data on the psychological measures’ skewness and kurtosis are presented in Table 2 of Supplementary Material. All P values presented are two-tailed.

Statistical analysis was divided into two sections: (1) description of the sample’s values across measures, throughout the experiment; and (2) analysis of the impact the tasks had on the subjects' psychological landscape.

In the first section, frequency (ie, absolute frequencies, percentages), central tendency (ie, mean, median) and dispersion (ie, standard deviation, range) measures are reported, as well as Cronbach alpha (discussed above). When relevant, means are compared with the minimum, maximum, and intermediate possible values of each scale, using a one-sample t test. This section concludes with the analysis of correlations between measures, using Pearson bivariate and partial correlations.

In the second section, we analyzed the direct impact the VR task had on affect, sense of presence, and the participants' performance regarding their situational awareness. To test for changes in affect, a Repeated Measures ANOVA was performed, complemented with Bonferroni correction for multiple comparisons. Sphericity assumption was assessed by the Mauchly's test, and as it was violated, the Greenhouse-Geisser F statistic was reported. To test for the impact of the VR task on the sense of presence, Pearson and partial correlations were conducted. Lastly, participants' situational awareness was analyzed using the QASA methodology.

All scales' descriptive statistics and Cronbach alphas values can be found in Table 2 of the Supplementary Material. The PANAS and ITC-SOPI presented after the CC2 have an *n* of 19 and 21 respectively, for the reasons previously mentioned.

Results

Participants

The majority were male (15/22, 68%), with a mean age of 39.1 years (SD 9.7; median 42.0, range 23-56), and completed the mandatory education in Portugal (secondary education) (17/22, 77%). Additionally, 91% (20/22) and 82% (18/22) of the sample reported consuming alcohol and coffee, respectively, and 36% (8/22) smoked regularly. Regarding their history of psychological help, 13 firefighters (13/22, 59%) reported having sought psychological assistance in the past. Concerning their activity as firefighter, the sample was equally distributed between professional (12/22, 55%) and voluntary (10/22, 45%) firefighters, working primarily in shifts (19/22, 86%), for a mean of 36.8 hours per week (SD 17.5; median 42.0, range 7-60). The participants inquired had worked for a mean of 18.9 years as firefighters (SD 10.6; median 18.0, range 4-40). Detailed sociodemographic data can be accessed online, in Table 1 of Supplementary Material.

Characterization of Psychological Measures

DASS-21

Participants' values in the three scales of DASS-21 were low, as all held normal depression scores (0 to 4), two had mild anxiety scores (4 to 5), and only one had mild stress scores (8 to 9). The sample mean for the Depression scale was 1.1 (SD 1.3; median 1.0, range 0-4), 1.2 for the Anxiety scale (SD 1.5; median 0.5, range 0-5), and the highest for the Stress scale (mean 3.7, SD 2.6; median 3.5, range 0-8).

QEPAT

Regarding the number of adverse events in the context of firefighting activities, participants had experienced a mean of 31.9 event types out of 42 (SD 4.5; median 33.0, range 23-40). No additional event was described by any participants.

The most frequently experienced adverse events were participating in firefighting activities where goods and properties were at risk (mean 2.7, SD 0.8; median 3.0, range 1-4), and aiding or seeing injured/fragile elderly (mean 2.7, SD 0.7; median 3.0, range 2-4.), with 59% (13/22) of the sample indicating experiencing each event many times or frequently. Additionally, 50% (11/22) of the sample indicated having seen or aided gravely injured adults many times, or frequently (mean 2.6, SD 1.1; median 2.5, range 1-4).

While analyzing the level of disturbance, we considered only the events the participants had experienced. The events that obtained the highest disturbance score mean was witnessing the death or grave injury of a firefighter colleague, while in active duty (mean 3.4, SD 0.7; median 4.0, range 2-4), and having aided a firefighter colleague who died or was gravely injured, while in active duty (mean 3.2, SD 0.7; median 3.0, range 2-4). Both of these were experienced by nine (9/22, 41%) participants. One other event type that obtained a high disturbance score and was experienced by all but one participant (21/22, 95%) was hearing through radio communications that firefighter colleagues were in danger, injured, or dead (mean 3.3, SD 0.7; median 3.0, range 2-4). Of the events witnessed by all participants, having seen or helped injured children was the one with highest level of disturbance (mean 2.2, SD 0.9; median 2.0, range 1-4).

PCL-5

None of participants surpassed the PCL-5 full scale thresholds, nor fulfilled DSM-5 criteria for possible PTSD diagnosis, yielding a sample mean of 3.9 scores (SD 4.5; median 2.0, range 0-12). The subscales had similar low mean scores. In the Intrusion Symptoms and Avoidance subscales, the sample held a mean of 1.0 (SD 1.5; median 0.0, range 0-5; and SD 1.9; median 0.0, range 0-8, respectively), being similar for the Negative Alterations in Mood and Cognition (NAMC) (mean 1.1, SD 1.7; median 0.0, range 0-6), and slightly lower scores for the Alterations in Arousal and Reactivity (AAR) subscale (mean 0.9, SD 1.3; median 0.0, range 0-4).

PANAS

Participants had low scores of Negative Affect for all four moments of administration of PANAS, ranging from a mean of 11.0 after both control conditions (SD 1.3 for CC1; SD 1.8 for CC2) to 11.9 (SD 3.2) after the experimental condition. All mean scores were lower than 12, although higher than the minimum score of 10 (P<.05 for all comparisons). Conversely, the scores on the Positive Affect scale were moderate to high. At the baseline measure (T0), the sample had a mean of 32.4 (SD 7.2), similar to the middle point of 30 (Cohen d=0.33, t_{21}=1.53, P=.14). The highest mean score was obtained for the measure after the second control condition (CC2) (mean 40.7, SD 6.6), although lower than the maximum scale-point of 50 (Cohen d=-1.42, t_{18}=-6.18, P<.001). Detailed results can be found in Figure 5.

CANTAB

All participants excelled in the Motor Screening Task (MOT), concluding the assessment trials with zero mistakes.

In the Spatial Working Memory task (SWMBE468 measure), the mean was -0.6, measured in normalized z scores (SD 1.3; median -1.0, range (-1.9)-2.3), which is only slightly lower than the norm mean of z=0 (Cohen d=-0.47, t_{21}=-2.22, P=.04). Only four (4/22, 18%) participants had values higher than the mean, with three obtaining the highest possible score of z=2.3 (percentile 99). These three participants never committed the mistake of revisiting a box in which a token had previously been found. The sample's median percentile was 15.5 (range: 3-99), with only 23% (5/22) of the sample on the percentile 42 or higher. Eight participants (8/22, 36%) were in the lower 10 percentile range.

In the Rapid Visual Information Processing (RVP) task, both the z scores of how good the participants were at detecting target sequences (RVPA) and the probability of false alarm (RVPPFA) were relatively low (RVPA: mean -0.5, SD 0.6; median -0.5, range (-1.4)-1.2; RVPPFA: mean 0.3, SD 0.9; median 0.1, range (-1.5 to -2.3). While the frequency of false alarms was similar to that of the norm (Cohen d=0.30, t_{21}=1.41, P=.17), our participants were slightly worse at detecting the target sequences (Cohen d=-0.81, t_{21}=-3.80, P=.001). Other three participants had a probability of false alarm of zero (percentile 99). In both measures, only one participant was in a percentile lower than 10 (8 for the RVPA, and 7 for the RVPPFA), who was also at percentile of 5 in the SWM task. The sample's median percentile for the RVPA measure was 29.5 (range: 8-89), indicating that half (11/22, 50%) of the sample had equal or worse capability to detect target sequences than the bottom 29.5% of CANTAB normative data.

Lastly, the sample's mean efficiency in performing the Intra-Extra Dimensional Set Shift task (IEDYERTA measure) was not different from the norm mean z scores (mean 0.0, SD 0.7; median 0.1, range (-1.3)-0.8) (Cohen d=-0.06, t_{21}=-0.28, P=.78). However, the participants' performance was heterogeneous, with a median percentile of 49.6, and the first and third quartiles at percentiles 28.8 and 68.5, respectively. Two participants (2/22, 9%) were in the percentile 9, which indicates that only 9% of the normative data committed more errors in this task than these participants.

No correlation was found between the CANTAB z scores and any relevant sociodemographic data (ie, sex, age, number of children, failing in school, alcohol and caffeine consumption, years in service, hours worked per week as a firefighter) (P>.05).

ITC-SOPI

The results for the ITC-SOPI scales were as expected. The highest mean was obtained for the Sense of Physical Space scale (mean 3.9, SD 0.8; median 3.8, range 2.9-6.4), followed by the Ecological Validity scale (mean 3.8, SD 0.6; median 3.8, range 2.8-4.8), and the Engagement scale (mean 3.8, SD 0.6; median 3.8, range 2.2-4.7). These scores were higher than the middle point of the scale (3) for all subscales (P<.001 for all comparisons).

Lastly, the Negative Effects scale had the lowest scores, with a mean of 1.7 (SD 0.6; median 1.7, range 1.0-3.0). This mean, although small, was higher than the lowest possible scale-point of 1 (Cohen d=1.25, t_{20}=5.71, P<.001). The most frequently mentioned negative effects were "feeling tired" (mean 2.1, SD 1.1; median 2.0, range 1-5) and "feeling disoriented" (mean 2.1, SD 1.0; median 2.0, range 1-4), followed by "ocular fatigue" (mean 2.0, SD 1.0; median 2.0, range 1-4).

Correlations Between Measures

At baseline (T0), Stress as measured by DASS-21, correlated positively with Negative Alterations in Cognition and Mood (NACM) (r=0.44, P=.04) and Alterations in Arousal and

Reactivity (AAR) (*r*=0.43, *P*=.04) of PCL-5, but not with the full scale scores (*r*=0.21, *P*=.34). The Stress scale additionally correlated positively with the Negative Affect scale of PANAS at baseline (T0) (*r*=0.42, *P*=.049) and after the second control condition (CC2) (*r*=0.46, *P*=.050). On the other hand, the Depression scale of DASS-21 correlated negatively with the Positive Affect of PANAS at baseline (T0) (*r*=-0.51, *P*=.01), and after each condition (CC1: *r*=-0.63, *P*=.002; EC: *r*=-0.54, *P*=.009; CC2: *r*=-0.70, *P*<.001). The Anxiety dimension of DASS-21 did not show any correlation with PANAS, for all moments measured.

Post-traumatic stress symptoms, as measured by the PCL-5, did not correlate with affect measures (PANAS), except after the experimental arousing condition (EC). Participants who held higher full-scale (*r*=0.43, *P*=.047), Intrusion Symptoms (*r*=0.53, *P*=.01), and Avoidance (*r*=0.71, *P*<.001) scores (measured by PCL-5 at baseline, T0) had increased Negative Affect scores, measured by PANAS after the EC. A partial correlation, controlling for Anxiety, Depression and Stress scores (DASS-21), confirmed this result (*r*=0.49, *P*=.04, *r*=0.51, *P*=.03, and *r*=0.75, *P*<.001, respectively). Conversely, even though it appears there is a negative relation between NACM (as measured by PCL-5) and Positive Affect (as measured by PANAS, after the EC) (*r*=-0.48, *P*=.02), this relation dwindles after controlling for the three DASS-21 scales (*r*=-0.45, *P*=.06). A similar result is found when relating the Avoidance symptoms scale (PCL-5) and the number of events experienced (as measured by QEPAT). While there appear to be a correlation (*r*=0.44, *P*=.047), it becomes non-significant after controlling for the DASS-21 scales (*r*=0.43, *P*=.08).

There was no significant correlation between any of the CANTAB and the QASA measures.

Direct Impact of the VR Training Task

Impact on Affect

Performing the VR task had a positive impact on Positive Affect, compared to the baseline (*Partial* η^2=0.52, *Greenhouse-Geisser* $F_{1.82,32.78}$=19.73, *P*<.001). The baseline (T0) Positive Affect was lower than that measured after CC1 (*P*=.004), EC (*P*<.001), and CC2 (*P*<.001). No differences were found between CC1, EC, and CC2 Positive Affect (*P*>.05). The Negative Affect scores remained consistent across the experiment, with no differences found between or after the VR tasks (*Partial* η^2=0.02, *Greenhouse-Geisser* $F_{2.13,38.4}$=0.39, *P*=.69). The results found for Positive and Negative Affect remain true when controlling for PCL-5 (full scale) and DASS-21 scales (Depression, Anxiety, and Stress) scores.

Impact on Sense of Presence

The mean results on the ITC-SOPI scales were positive, as aforementioned. These positive results are highlighted when relating to the affect felt throughout the VR tasks and after the experiment ended, controlling for Positive and Negative Affect at T0 (baseline).

When considering the Positive Affect reported after all VR tasks were completed (ie, at the end of the experiment, after the second control condition (CC2)) and its relation to the ITC-SOPI scales, a positive correlation emerges solely with the participants' reported Engagement (r=0.55, P=.02). Contrarily, the Negative Affect reported correlated positive and significantly with the Negative Effects of the VR task as measured by ITC-SOPI, both after the first non-arousing control condition (CC1) (r=0.61, P=.01), and at the end of the experiment (ie, after CC2) (r=0.53, P=.03). This is in accordance with the correlation found between the Negative Effects scale of ITC-SOPI and other scales. Specifically, a positive and moderate relation was found between the Negative Effects and Avoidance scores (r=0.73, P<.001), controlling for baseline levels of depression, anxiety and stress (DASS-21 scales) and for the number of adverse events experienced (measure obtained with the QEPAT questionnaire). No significant correlations were found between any ITC-SOPI scale and the Positive or Negative Affect reported after the arousing experimental condition (EC). Recognizing how idiosyncratic differences in baseline affect could bias results, all of the aforementioned results do therefore represent partial correlations.

Another noteworthy correlation found was between the number of events the participants reported having experienced (QEPAT) and the Engagement subscale (ITC-SOPI) (r=0.49, P=.02). It appears that participants who experienced more events while in active duty, have also considered the VR setting more engaging.

Impact on Situational Awareness

Regarding results on the QASA tool, the sample had overall positive results, obtaining a mean rate of correct responses (ie, hit and correct rejections) of 68% (SD 14.6; median 64.3, range 43-93). This mean rate is similar for the hit (mean 68.2, SD 21.1; median 71.4, range 29-100) and the correct rejections (mean 67.5, SD 12.6; median 71.4, range 43-86). In accordance, the mean rate of incorrect responses was relatively low, at 32% (SD 14.6; median 35.7, range 7-57), both for the rate of misses (mean 31.8, SD 21.1; median 28.6, range 0-71) and false alarms (mean 32.5, SD 12.6; median 28.6, range 14-57).

Comparably, the mean actual situation awareness, as measured by A', was relatively high (mean 46.4, SD 34.5; median 45.0, range (-25.0)-92.9), with only one participant having an A' value lower than 0 (A'=-25). This indicates that the overall sample has a good situational awareness, regarding the elements present in the VR task simulation, and is able to distinguish true from false information (with the exception of one participant).

These results were in tandem with the perceived confidence of the participants in their answers (PSA). The sample's perceived situational awareness mean was 47.2 (SD 25.0; median 47.6, range 0-100). All but one participant had confidence in their ability to detect the correct response, as they obtained positive values and only one reported not being very confident (ie, PSA value of 0).

When comparing the difference between A' and PSA (perceived situational awareness) scores, it is possible to see that, although no difference between the means was found (mean difference -0.8) (Cohen d=-0.02, t_{21}=-0.08, P=.94), there was a great amount of variation between participants (SD 45.0; median -12.6, range (-61.9)-83.3). Thirteen (13/22, 59%) participants perceived their situational awareness as being higher than it was (reflected by a negative difference), while nine (9/22, 41%) had higher situational awareness than they themselves perceived having (as reflected by the positive difference).

The sample presented a slight information acceptance bias, with a mean of -13.6 (SD 30.3; median 0.0, range (-100.0)–9.1). Two (2/22, 9%) participants had B'' values of -100, indicating a great tendency to accept information as true, even if false. Eight (8/22, 36%) participants did not have any bias, as they had a B'' value of 0.

Concordantly with the aforementioned results, no correlation was found between the actual situational awareness (A') and the perceived situational awareness (PSA) (r=-0.12, P=.59). The same result was found when controlling for experience (ie, years as a firefighter) (r=-0.11, P=.63). PSA values did also not correlate with the bias scores (B'') (r=0.19, P=.41). The only correlation found was between A' and B'' scores (r=-0.51, P=.02), even after controlling for years in service (r=-0.50, P=.02).

Table 2 displays the summary of the main findings of the present study.

Table 2

Summary of Findings

Variables of Interest	Main Findings
Affective State	Virtual Reality increased positive affect, keeping negative affect low and constant throughout the training.
Effects of VR	Engagement with the task was high, with few negative effects. Participants

	reported the VR setting provided the sense of being in a physical space and had high ecological validity. Engagement was highest for firefighters who had previously experienced more adverse events while in active duty.
Situational Awareness	The firefighters had good situational awareness of which elements were present in the VR setting (and which were not), although they had a slight inclination to accept that the elements were present, at face value. Some participants overestimated how good their awareness was, while others underestimated it.

Discussion

Principal Results

The present study showed the viability of a VR firefighter training tool as a valid serious games approach to act as an alternative for in-person real-life training, which can endanger the firefighter's life and garner limitations in the training situations available. Furthermore, the VR setup used in the present study allows for ecologically valid and immersive scenarios, which is an advantage for realistic training that prepares for real-life situations.

Participants' level of acceptability is a crucial aspect to consider for VR usage. Many reasons can explain the low tendency to integrate VR settings, namely skepticism, vulnerability, insecurity, lack of ease to interact with the equipment [81] or absence of realism [25]. Kari and Kosa [82] presented an interesting model joining hedonic and utilitarian/inconvenience measures to explain use and acceptance of VR games, supported by the subjects' behavioral intention to use that was influenced by curiosity and enjoyment. Another relevant aspect is that perceived ease of use was correlated positively with perceived usefulness, curiosity, enjoyment, and control, and negatively associated with discomfort; in turn, utilitarian health and well-being factors were less significant aspects in terms of use of VR games applications.

In the present study, this VR task was well received by the participants, in accordance with a previous study using the same VR apparatus (eg, [77]). Positive affect increased compared to baseline, just by performing the VR task. This was independent of the type of scenario. That is, it appears that being immersed in the VR setting itself improves positive affect, being the scenario neutral and not requiring immediate action (preparing the surroundings of a house for a forest fire), or requiring urgent action and being arousing (putting out a house fire). This is corroborated by the relation found between the positive affect and engagement, both reported at the end of the overall VR task and both yielding highly positive means. This reflects that engagement with the overall VR task increased as positive affect increased, and vice versa. This is true, regardless of idiosyncratic differences in baseline positive and negative affects. For VR training to be successful, the firefighters have to be engaged with the task, which could be related to positive rather than negative affect. Indeed, a recent systematic review and meta-analysis demonstrated the positive impact of VR environments in positive and negative affects, measured with the PANAS measure [83]

Another aspect for the success of the VR firefighter training is the positive feedback from participants regarding the simulation itself. At the end of the study, participants reported that the simulations were perceived as real and similar to the real world, which was reflected by the high mean scores regarding the sense of physical space and ecological validity, among the reported usefulness for training and learning purposes. This adds to the existing literature that has demonstrated how VR increases the ecological validity of experiments [6], and allows the transfer of skills from VR to real-world scenarios [7–9].

In the present study, the realness (given by ecological validity scores) of the VR simulations was independent of both the positive and negative affects felt by the participants, which attests to the validity of the simulation being independent of the participant performing it. Similar results were found with VR applied to higher education purposes. The study showed that the level of immersion is crucial for students' sense of presence and positive affect (also, measured by PANAS). Our results contribute to the generally accepted premise that VR has a positive impact on users' learning and training outcomes (eg, [83]). In the same line, Shafer and colleagues [84] presented a model, explaining how enjoyment is produced in VR applications. The authors argued that subject's perceived interactivity predicts spatial presence and realism in the task, while realism independently predicts spatial presence, and in turn spatial presence predicts enjoyment; cybersickness was included as a covariate influencing enjoyment, and previous exposure using VR or similar experience was a weak impact on cybersickness.

Another point to consider regarding the viability of VR firefighting training is the dampening of negative effects. It could be argued that the positive effects might be surpassed if the use of VR leads to greater distress, discomfort, or puts into question the health of the participants. In the present study, we found no validation for this tenet. On the contrary, participants' negative affect remained low at baseline and throughout the VR task, with no impact of the arousing, urgent house fire scenario. These results (demonstrated by the firefighters' positive feedback and low negative emotions) are congruent with the principal dimensions highlighted in a very recent study - usability, usefulness, fun and joy - as critical aspects to adopt and recommend VR experiences [85].

Nevertheless, a positive relation was found between the participants' avoidance, a symptom of PTSD, and the negative affect reported after the arousing scenario. Similarly, participants who reported experiencing symptoms of avoidance more frequently, were also the ones who indicated having felt more negative effects due to the VR simulation. This is true, regardless of the number of advents experienced and of depression, anxiety or stress symptomatology. This finding should be further explored to ensure that even firefighters who demonstrate some PTSD symptomatology can perform the VR task and are not vulnerable. Additionally, while one might expect that experiencing a greater number of adverse events would deter firefighters from engaging in a VR simulated firefighting environment, the contrary was found. The participants who reported feeling greater engagement with the VR tasks, were the ones who had experienced an increased number of adverse events. Some explanations can be posited in this regard. Indeed, having experienced some stress levels during activity and confrontation with adversity could lead to greater motivational status to improve this state of affairs and mobilize participants to act and manage situations, suggesting specific coping strategies and resilience mechanisms - [85]). This topic gains significant importance with implications for intervention strategies, namely the relevance of including approaches to boost mechanisms of emotion regulation in firefighters, for example stress buffer interventions or improving distress tolerance programs, as proposed by Stanley and colleagues, who highlighted the positive role played by distress tolerance on occupation stress and suicide risk among 831 firefighters [40].

Nevertheless, the participants reported feeling sparse negative effects due to the VR task alone. The most frequently mentioned effect was "feeling tired", which might be attributed to the complex implementation of this study itself. Due to the plurality of physiological, and psychological measures taken throughout the VR task, the participants had more equipment on them than they would in other VR training contexts, and expended more time than usual between scenarios in order to complete questionnaires. Moreover, this negative effect can be reduced by not performing several VR scenarios in a single training session, thus diminishing fatigue. Regarding the "ocular fatigue", the second most mentioned negative effect, it is something that is expected to subside as technology improves. As expected, negative *affect* measured after most of the VR tasks (Control Conditions) was related with the negative *effects* reported, both being minute.

The positive and negative emotional experience found in this study was congruent with the results found in a sample of trainees using a VR training system for fire extinction [25].

To further explore the reliability of VR training, it is relevant to assess firefighters' performance in this task. For this purpose, the QASA tool was developed. It has a twofold objective:

it both allows to assess if firefighters are aware and attentive to the elements present in the simulation, and validates that the firefighters are really attentive to the VR task as if it were a real-life scenario. Participants were successful in this task, as they managed to identify correctly most of the elements that were true (ie, hit), and most which were false (ie, correct rejections). However, this alone does not allow to infer on their awareness of the simulation situation. To assess their actual situation awareness, the emphasis should be on the A' measure, which can be interpreted as a measure of "an individual's knowledge of the situation as compared to the "ground truth" ([71]). The participants' situation awareness was high, indicating that the overall sample is attentive to the simulation and can identify which statements addressing the simulation are true, and which are false. This supports the fact that the participants were paying attention to the simulation. But are the participants aware of their own situation awareness? Although the sample's mean of the perceived situation awareness was similar to their actual situation awareness, there appears to be no correlation between the two, suggesting that performance self-appraisal is not accurate in this setting. In fact, approximately half of the participants overestimated how good their awareness was, while the other half underestimated it. This is especially surprising considering how all but one participant was confident that most of their responses were correct, some even indicating all their responses were correct. This result, although expected, has major implications, as awareness of the situation is a necessity when it comes to firefighting. Not being attentive to the details of a situation can be the difference between life and death in a real-life scenario. Lastly, the majority of participants showed almost no bias in information acceptance. That is, they were considerate when responding to the questions, and did not simply accepting all information provided as being true or as being false.

Concerning the firefighters' emotional and cognitive characterization, a few depressive, stress, and anxiety symptoms, showed some relation with other measures. For instance, stress levels were related to some PTSD symptoms. Participants who had higher values of negative alterations in cognition and mood (NACM) and alterations in arousal and reactivity (AAR), also had higher stress values, which was to be expected. Indeed, in the systematic review performed by Jones [36], a plurality of studies found high comorbidities in firefighters.

Furthermore, participants with higher stress scores additionally reported increased feelings of negative affect (both when the study started, before the VR task, and after the VR task was finished). While anxiety scores appear to not have any relation to any of the other measures, the depression level reported had an inverse pattern to the positive affect throughout the experiment. That is, the more the participants felt depressed, the less positive their emotional state was. Notwithstanding, this seems to reflect more on the participants' typical emotional state, than on the VR task success and impact. Nonetheless our sample showed few indicators of psychopathology (as measured by DASS-21 and PCL-5), which goes in accordance with results from a sample of 312 Portuguese firefighters, who reported low scores of depression, anxiety and stress using the same measure used in this study and high levels of happiness [86]. The mental health of firefighters is an issue of particular relevance [37], which cannot be neglected, and is emphasized by the aforementioned findings.

In this regard, serious games applied to interventions have been revealing promising results in clinical settings, namely by promoting treatment and recovery of serious mental illness [87]. Regarding trauma, a recent study showed a contribution towards showing increasing users' awareness of psychological trauma, their sense of security and promotion of seeking specialized help [88]. Another study using a computer game showed potential to reduce intrusive memories of a traumatic event [89]. Positive results with a VR simulator were experimented by two truck drivers with PTSD [90]. This literature suggests a high potential for PTSD treatment using the innovative elements of Virtual Reality.

Regarding the participants' cognitive performance, none demonstrated having any sensorimotor deficits nor lack of comprehension, measured by MOT test as recommended [49]. Regarding their performance on the remaining cognitive tasks, the capability to not be swayed by false alarm sequences in the rapid visual information processing task (RVPPFA measure) and their ability to shift between intra and extra dimensions of a stimuli (IED test) (ie, the ability to discriminate between visual set formation and to maintain or shift attention, in accordance with environmental clues) were no different than the sample norm. On the other hand, on average, firefighters performed the worst on the spatial working memory task (SWM test) (ie, remembering which boxes were previously searched), and the ability to detect rapidly shown number sequences (RVPA measure) during rapid visual information processing.

These measures were explored, as they convey cognitive functions that are at play when putting out fires. Spatial working memory, strategic planning capacity by trial-error, attention and rapid visual processing, abstract thinking, and the cognitive flexibility ability to shift attention between elements of stimulus following environmental clues through an organized searching are all competencies needed when firefighting, as rapid decision-making and problem-solving are demanded. Although questions could be raised regarding the ecological validity of transposing this concise cognitive assessment to a real-life situation, it also brings into deliberation the need to assess a firefighter's strengths and vulnerabilities when appointing a position in action. Questions of ecology are highlighted by the fact that no correlation was found between any of the aforementioned CANTAB measures and the QASA measures.

Comparisons with Prior Work

According to previous work, VR serious games systems have high potential for training purposes, giving the possibility to customize directly in accordance with the users' needs [2]. In the present study, two realistic scenarios (and widely related to daily duties of firefighters) were selected in order to ascertain the impact on induced positive and negative affects. On one hand by neutral and non-urgent duties (preventive tasks), and on the other hand urgent, stressful and arousing activities, namely to extinguish a house fire and rescue victims.

During these tasks, firefighters had the opportunity to practice and develop their skill set (eg, dynamic thinking, stress management, decision making under pressure conditions, risk assessment, fire control, hose handling technique and nozzle control), learn and experience in a safety immersive environment, which might not be possible to replicate in real life. These were advantages of VR compared to traditional training, according to several authors (eg, [2,10,11]). Other features of these systems demonstrated during this study were the capacity to maintain motivation and users' engagement (eg, [13]. Indeed, participants reported adequate levels of physical presence, ecological validity and engagement at the end of the experience, and residual negative effects, in accordance with previous studies with Portuguese firefighters (eg, [9,15,30,35]). Furthermore, while performing the tasks, several firefighters provided additional feedback which supported the system's reality, as similar to real-life work, as recommended in the literature (eg, [15,23]), presenting acceptability and emphasizing its usefulness, in congruence with other studies (e.g., [82,85]. Additionally, emotions, a crucial dimension to consider in VR experiences as argued by Saghafian and colleagues [25], were monitored at baseline, between scenarios and immediately after, showing consistent effects. Collectively, these results demonstrate reliability of the experiment.

Regarding cognitive performance, some studies showed the negative impact of a shift-work regimen on cognitive functions, which is frequent among Portuguese firefighters (approximately 86% of our sample are shift-workers). In general, our sample revealed normative performance across the majority of tests, which is in line with considerations of a study conducted with firefighters [44]. These authors assessed cognitive functions using three different tests (Paired associates learning, Reaction Time and Spatial span) of the CANTAB software in simulated hot conditions, and further noted that some of these tasks were probably quite easy for their healthy sample of wildland firefighters.

Lastly, another key aspect in firefighters' performance is their actual situational awareness and how good they perceive it to be, that is their performance self-appraisal (a metacognitive ability).

As Edgar and colleagues [71] note, the correlation between the actual and perceived situational awareness is inconsistent in the literature, sometimes being negligible, as in the present study. They further highlight several studies that show performance is moderated by how good the participants believe their situational awareness to be, independently of whether their assessment is correct. They hypothesize the inconsistency between studies might be explained by a lag between the measurement of actual and perceived situational awareness. This explanation does not fit the present study, as both measures were collected in the same moment. Nevertheless, efforts should be made, not only to improve the actual situational awareness of firefighters, but also to align their perception to their actual awareness.

Limitations and Future work

This experiment was conducted for research purposes. Although precise instructions were provided for participants to act exactly like doing firefighting in real life, these findings should be viewed with this caveat. Despite the greater levels of ecology and presence revealed by the experiment, fighting a fire and rescuing victims in simulated situations will never be exactly the same as in a real-life situation. In the same line, albeit the cognitive dimensions assessed are valuable skills for performing fire duties, some caution is needed when transferring these outputs to real practice, as it was obtained through computerized abstract tasks. In addition, considerations should be made to the experimental setting itself. As previously mentioned, the experiment involved performing a complex set of diverse tasks (neuropsychological session followed by three moments of immersive VR scenarios with simultaneous measurement of biosignals), requiring that participants have to wear non-usual equipment (eg, electroencephalography, EEG cap, respiration band) during task performance and involving a wide range of resources. These constraints may challenge ecological transposition for real firefighting activity and could cause fatigue among participants. Albeit this limitation, these were requirements of the experimental design and pauses between procedures were implemented. However, to reduce this potential concern, future work should consider reviewing the time of the experiment, including the duration of the simulation.

The impact of the psychological assessment on the participants' performance on the VR task should also be considered in future work. Although the protocol was designed to avoid bias due to mood-congruent memory recall [54], it is possible that completing the PCL-5, DASS and CANTAB before the VR task could induce fatigue and negative associations from past experiences, and have impacted the participants' VR experience. It is recommended that this interplay between the psychological assessment and VR task is further explored in future research.

One other aspect not accounted for is the level of experience the firefighters have with VR specifically and gaming in general. In our case, participants had a moderate level of experience on immersiveness. Previous research has found that the level of experience and age of the participants influences their immersion within the VR setting [91]. Even though this was not the focus of the present study, it is an aspect that could lead to a heterogeneous experience for individuals or different experience levels and should thus be further investigated in future research.

A final aspect which is worth mentioning – many firefighters have stated that each member of their firefighter corporation has a specific role attributed inside the team, when deployed in the field of operations. In future work, this issue might be considered including multi-player tasks, in order to achieve the most realistic situations, similar to the prototypical VR system using a multi-user training application among maritime firefighters [19]. Collaboration between members, communication skills and collaborative work could also be addressed, even more, as target abilities of being a firefighter. These are skills easily promoted by opting for VR training settings [14], rather than in-person methodologies.

Conclusions

An innovative multicomponent approach was applied to a sample of Portuguese healthy firefighters, considering psychological variables, cognitive indicators including situational awareness ability, combined with a haptic realistic VR training system, and simultaneously coupled with physiological measures. Considering that firefighters are a population at high risk, negative affective states of depression, anxiety and stress were considered, as well as severity of PTSD symptoms and adversity witnessed as a firefighter. This is relevant because Portugal is a country annually ravaged by wildfires, with uncalculated costs at various levels.

Promising results were found, as participants were engaged during all tasks, revealing high levels of motivation and acceptance related to the VR software. The ecological validity of both immersive scenarios was supported (irrespectively of facing neutral or arousing stress-inducing conditions), with a positive impact (positive affect was higher after the experiment) that could buffer the minor negative effects reported, when PTSD symptom severity and anxiety, stress and depression were controlled for. In general, the sample demonstrated adequate cognitive abilities and awareness to significant elements of the situations, even though not corresponding exactly to their perception.

These results attest to the VR translatability to the real-world, as a valid cost-effective alternative to traditional in-person training, closer to the specificity of firefighter activity. The use of innovative technologies, such as the haptic and immersive VR software used here, was attested for firefighter training and learning purposes, and complemented the prior work, combining several

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methodologies in a multicomponent approach. Additionally, serious games and VR immersive tools might be put at the disposal of professional corpus to improve work conditions.

Valid contributions for this field of study emerged. Practical implications for real-world practice are important, in relation to the impact of being a firefighter, as well the consequences of daily-duties, and identification of variables that have to be taken into account for improving training programs fitted to the demands of the firefighting work and the daily challenges faced.

Acknowledgements

This study was supported by grants by FCT (Foundation for Science and Technology; in Portuguese, Fundação para a Ciência e Tecnologia), cofinanced by FEDER, the Portuguese Foundation for Science and Technology, PCIF/SSO/0082/2018, DSAIPA/DS/0041/2020, FCT/UIDB&P/4950/2020.
The authors would like to thank the Portuguese National Fire Service School (Sintra pole, Portugal) team and all firefighters who collaborated on this study. Also, the multimedia and reporting team, authors of the two images of firefighters' performance during experiments, which were included in this work.
The authors are grateful to Ana Dionísio (a former CIBIT collaborator) who collaborated in experiments and supported the team during initial VR experiences. Also worthy of mention are the psychologist Salomé Caldeira, PhD and the psychiatrist João Redondo, MD, from the Centre for Prevention and Treatment of Psychological Trauma (CPTTP), Coimbra University Hospital Centre (CHUC/ ULS Coimbra), who provided expertise in the stress and trauma field. Also, the Portuguese authors who gave permission for using the instruments here. Finally, the authors would like to acknowledge the FLAIM systems team who provided technical support to the FLAIM Trainer simulator system, in particular to James Mullins and Martijn Boosman.

Authors' Contributions

VR and RP were responsible for recruitment by contacting the firefighter fire stations and scheduling participants' sessions, at the Portuguese National Fire Service School. JO, JAD, RC, MS and MCB designed the study, with validation from VR and RP. JO designed the neuropsychological protocol, with direct collaboration of JAD. JO, JAD, RC, DS, and DA collected the data. JAD organized the database, with direct collaboration of JO. JAD performed the statistical analysis. MCB, JO, and JAD wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

Conflicts of Interest

Non declared.

No generative AI was used in any section of the manuscript writing.

Data availability statement

Some restrictions apply given the use of personal psychological evaluation data. Data will made available upon reasonable request to the corresponding author.

Abbreviations

AAR: Alterations in Arousal and Reactivity

CANTAB: Cambridge Neuropsychological Test Automated Battery

CC1: Control condition 1

CC2: Control condition 2

DASS-21: Depression, Anxiety and Stress Scale - 21 Items

EC: Experimental condition

ICNAS: Institute for Nuclear Sciences Applied to Health

IED: Intra-Extra Dimensional Set Shift

ITC-SOPI: ITC-Sense of Presence Inventory

MOT: Motor Screening Task

NA: Negative affect

NACM: Negative Alterations in Cognition and Mood

PA: Positive affect

PANAS: Positive and Negative Affect Schedule

PCL-5: PTSD Checklist for DSM-5

PTSD: Post-traumatic stress disorder

QASA: Quantitative Analysis of Situation Awareness

QEPAT: Questionário de Exposição e Perturbação dos Acontecimentos Traumáticos (in Portuguese), a questionnaire related to the exposure and disturbance of traumatic events

RVP: Rapid Visual Information Processing

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SWM: Spatial Working Memory

VR: Virtual reality

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Figure legends

Figure 1. Diagram of the recruitment procedure and experimental sessions, including psychological assessment, virtual reality experiments and biosignal recorder.

Note: T0 – baseline; CC1 – Control condition 1; EC – Experimental Condition; CC2 – Control condition 2; PANAS - The Positive and Negative Affect Schedule; DASS-21 - Depression Anxiety Stress Scales- 21 items; CANTAB - Cambridge Neuropsychological Test Automated Battery; QEPAT - – (in Portuguese: Questionário de Exposição e Perturbação dos Acontecimentos Traumáticos, a Portuguese questionnaire related to the exposure and disturbance of traumatic events); PCL-5 - PTSD Checklist for DSM-5; QASA - Quantitative Analysis of Situation Awareness ITC-SOPI - ITC-Sense of Presence Inventory.

Figure 2. Two firefighters perform the VR tasks (images from the Portuguese National Fire Service School).

Figure 3. Scenario of the Control Conditions – CC1 and CC2 conditions (provided by FLAIM).

Figure 4. Scenario of the Experimental Condition – EC condition (provided by FLAIM).

Figure 5. PANAS scores across the study (T0, CC1, EC, CC2).

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Note: T0 – Baseline; CC1 – Control condition 1; EC – Experimental condition; CC2 – Control condition 2

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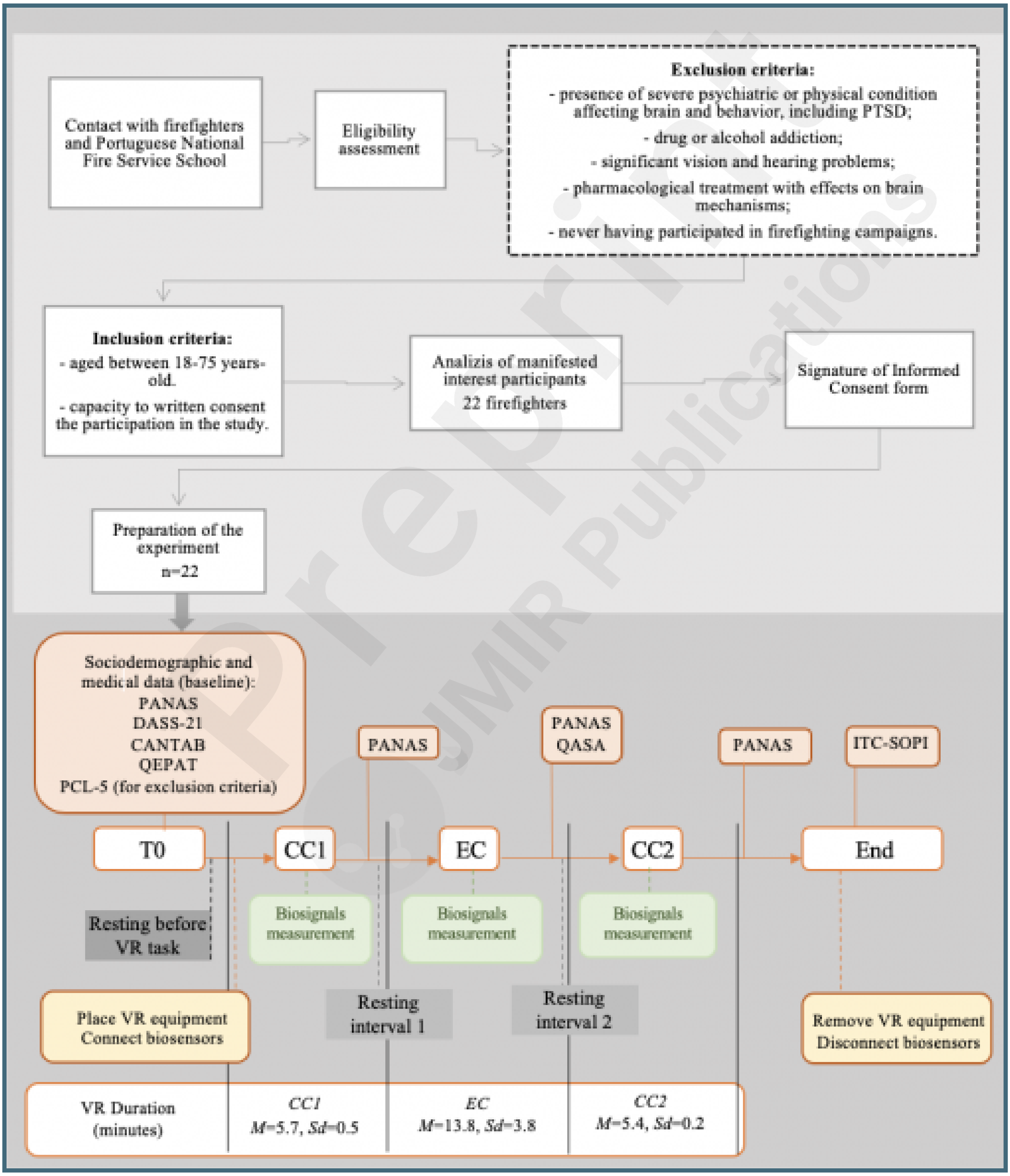
Supplementary Files

Figures

Diagram of the recruitment procedure and experimental sessions, including psychological assessment, virtual reality experiments and biosignal recorder. Note: T0 – baseline; CC1 – Control condition 1; EC – Experimental Condition; CC2 – Control condition 2; PANAS - The Positive and Negative Affect Schedule; DASS-21 - Depression Anxiety Stress Scales- 21 items; CANTAB - Cambridge Neuropsychological Test Automated Battery; QEPAT - – (in Portuguese: Questionário de Exposição e Perturbação dos Acontecimentos Traumáticos, a Portuguese questionnaire related to the exposure and disturbance of traumatic events); PCL-5 - PTSD Checklist for DSM-5; QASA - Quantitative Analysis of Situation Awareness ITC-SOPI - ITC-Sense of Presence Inventory.

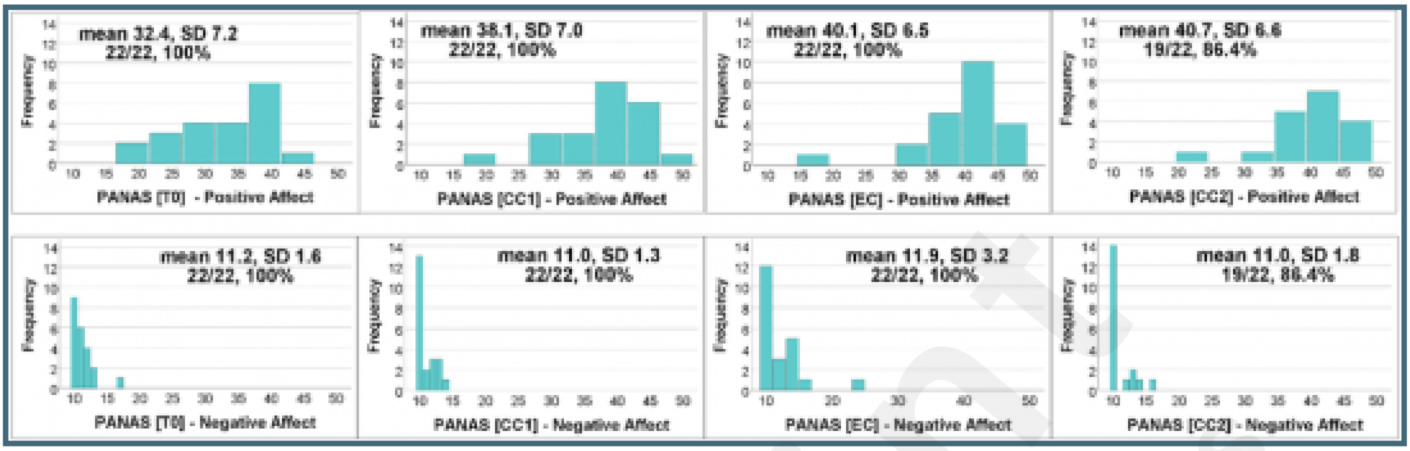


Two firefighters perform the VR tasks (images from the Portuguese National Fire Service School).

Scenario of the Control Conditions – CC1 and CC2 conditions (provided by FLAIM).

Scenario of the Experimental Condition – EC condition (provided by FLAIM).

PANAS scores across the study (T0, CC1, EC, CC2). Note: T0 – Baseline; CC1 – Control condition 1; EC – Experimental condition; CC2 – Control condition 2.



Multimedia Appendixes

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Supplementary Table.
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