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A framework and serious game for decision making in stressful situations; a fire evacuation scenario

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A R T I C L E I N F O

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A B S T R A C T

Decision making is a core cognitive process of human behaviour that is often affected by stress. Whilst we make several decisions on a daily basis, firefighters in particular are called to make important decisions in a split second and within life-threatening settings. Stress can therefore impact their ability to perform and carry out their job. The implications of stress are similarly important in other settings requiring high-vigilance. In this paper, we aim to contribute to efforts to better train firefighters in decision making in stressful situations through a serious game solution. The game was designed based on the Stress Exposure Training (SET) approach and in accordance with typical stressors identified in the literature. Those were then mapped to relevant game mechanics. The evaluation of the resulting game was twofold: A. to assess its ability to increase participants' stress level, and B. to investigate whether decision making performance would be improved for participants under stress. The proposed framework and the prototype were evaluated through empirical research that consisted of the participants' self-reported stress levels using the State-Trait Anxiety Inventory for Adults (STAI) and the participants' physiological measurements, namely galvanic skin response (GSR) and heart rate (HR). Our results demonstrate the potential of serious games to assist towards training of firefighters to make better decisions under stressful situations. Our findings are of wider importance as they contribute to ongoing efforts to improve decision making under stress in a variety of settings and scenarios.

1. Introduction

We make hundreds of choices everyday. It is estimated that an adult makes approximately 35,000 conscious decisions each day (Sahakian and LaBuzetta, 2013) in various settings including, but not limited to, personal and professional practice. Decision making is considered a core cognitive process of human behaviour and can be defined as the process of choosing an option or an action from a set of alternatives based on criteria or strategies (Wang et al., 2006; Wilson and Keil, 2001).

It is common that many decisions are often made under stressful situations (Starcke and Brand, 2012). The Mental Health Foundation defines stress as "the feeling of being overwhelmed or unable to cope with mental or emotional pressure", which is triggered as a result of experiencing something new or unexpected (Mental Health Foundation, 2021). This is the definition we adopt in this work and we particularly focus on the emotional (physiological) responses to environmental and emotional pressures.

Research has shown that there is an association between stress and decision making, which is often of a negative nature (Galvan and Rahdar, 2013; Staal, 2004; Starcke et al., 2008). Indeed, past work by Starcke and Brand (2012) identified that the effects of stress on decision making can have a lasting impact to public health by increasing the risk for unhealthy decisions, such as smoking, drinking or an unhealthy diet. Similarly, stress can have a negative impact on situations of vigilance such as natural disasters, fire or war which can be life threatening, as they require a person to make decisions in quick succession to avoid potential catastrophic consequences (Williams-Bell et al., 2015). It is therefore evident that making decisions under stress can and often leads to undesirable results such as increased distraction and increases in reaction time due to hurried decision making (Driskell et al., 1999).

In particular, firefighting personnel experience decision making under stressful situations on a daily basis. Past research revealed that emergency services personnel demonstrated lack of cognitive functioning due to stress, which resulted in second-guessing judgements (Baker and Williams, 2001). Fire departments are therefore naturally concerned about the negative effects of stress on their personnel's

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decision making and performance. In fact, the negative association between decision making and stress has been extensively researched in the past, as evidenced in the body of research (Driskell et al., 1999; Gok and Atsan, 2016; Starcke and Brand, 2012). However, enabling individuals to prepare themselves about how to make the right decisions in stressful scenarios is an ongoing area of research (Phillips-Wren and Adya, 2020; Sun and Sekuler, 2021).

Accordingly, this paper aims to address the above issue through a serious game solution for a fire evacuation vigilance scenario. Serious games which are defined as digital games that do not have entertainment as their main focus, have been shown to be an effective platform for improving training, education or modifying objectives (Michael and Chen, 2005). As such, they have been successfully applied to a wide range of scenarios, as they have been found to be captivating and they have been proven to statistically contribute to better decision making (Clark et al., 2020; Czauderna and Budke, 2020; Mendonca et al., 2006). Specifically, the aim of this work is to investigate whether a serious game solution could be an effective approach to induce stress and at the same time improve decision making performance of firefighters with a view on ultimately helping towards efforts to prepare them for emergency scenarios.

This paper is structured as follows. Section 2 presents previous work on decision making, stress and relevant serious games. Section 3 then discusses the design and implementation of the game, whilst Section 4 presents the user evaluation. Finally, Section 5 identifies the main findings and contributions from this work.

2. Related work

In this section, previous work on decision making, stress training, serious games, and Game Design Frameworks are presented.

2.1. Decision making and stress

A number of theoretical models on decision making behaviour under stress are available in the literature, namely the conflict-theory of decision making, the threat-rigidity effect model, the crisis model, and the decision making under time pressure model (Gok and Atsan, 2016). Whilst each model presents a different approach to the study of decision making under stress, they all agree on certain sources of decision-specific stress that are common amongst them - the perceived level of threat, the decision context, and the decision maker.

Similarly, from a methodological perspective, the process by which humans make decisions can also be affected by stress. Robbins and Coulter (2012) describe an 8-step process which is followed to make a decision, namely identify a problem, identify decision criteria, allocate weights to criteria, develop alternatives, analyse alternatives, select an alternative, and implement the alternative. Along the same lines, Kowalski-Trakofler et al. (2003) discuss a similar process consisting of five steps, namely recognise problems or objectives, generate alternative courses of action, evaluate and/or rank possible alternatives of action, make a choice from among them, and implement the selected course of action.

Evidently, stress has been shown to impair both the decision making process and the decision making behaviour. It is reasonable, therefore, to hypothesise that if stress could be moderated, then decision making could be improved as a result. Indeed, past research has found that stress handling could be improved through practise depending on the scenario and context (Driskell et al., 2008). This work is build upon this premise and aims to train firefighters in stress coping, which ultimately could have a positive effect in their decision making.

2.2. Stress training

A number of stress training approaches across various application areas have been proposed in the literature. Past research challenged the applicability and usefulness of such approaches to task-based skills training under stressful scenarios. This work will be based on the **Stress Exposure Training (SET)** approach described by Driskell (Driskell and Johnston, 1998), as it has been found to be able to train individuals in more generalizable factors than task skills, such as controlling perceived stress and workload by managing stressors, as well as by providing information on how stress affects task performance (Ross et al., 2004). The latter is particularly important to firefighters as their performance can be impacted by stress-related factors (Baker and Williams, 2001).

Stress Exposure Training consists of a three-phase process, namely 1. information about the stress environment, problem stressors, and their effects, 2. skills acquisition and coping, and 3. application and practice of skills in a simulated environment that reproduces the identified stressors (Ross et al., 2004). The identification of relevant stressors is paramount in this process. (Staal, 2004) usefully summarised stressors that are typically present in tasks of vigilance (Table 1), such as the ones that firefighters are subjected to where they are required to maintain high levels of attention for prolonged periods. The effect of stressors on vigilance can lead to errors of commission and errors of omission, depending on the type of the stressors and their impact on arousal level (Carmen, 1998). Stressors such as fatigue, lack of sleep and heat lead to increases in errors of omission, whilst time pressure, increased workloads and noise tend to lead to increases in errors of commission (Corrigan et al., 2021).

Specifically, in vigilance situations such as fire, which can be both life-threatening and stressful, managing an emergency requires effective coordination and communication (Chen et al., 2008) in order to solve the problem at hand. However, the research findings regarding the negative effect of the aforementioned stressors in tasks of vigilance are clear; vigilance tasks, attention and performance were the most negatively affected due to stress.

In addition to the above stressors, vigilance situations typically require a significant investment of mental effort whilst working on vigilance-related tasks. It has been shown that the perceived complexity of such tasks (i.e. mental load) and this invested mental effort are characteristics of an individual's cognitive load, which can impact on an individual's ability to learn or perform a task (Minkley et al., 2021). A number of cognitive load causal factors have been identified in the literature, which can be related to learner characteristics (e.g. prior knowledge, motivation), learning task (e.g. complexity, time pressure), physical learning environment, and emotion (e.g. stress, enjoyment) (Choi et al., 2014; Plass and Kalyuga, 2019). One of the challenges in situations of vigilance is that cognitive processing could be hard due to the expected load on an individual's senses.

It is expected that both stressors and cognitive overload can affect decision making in emergency situations. Therefore, allowing stakeholders involved in such situations to be able to prepare and cope with relevant problem stressors and cognitive overload in advance and whilst out of direct harms reach would be an ideal setting. Serious games can be an effective solution to this respect, as they typically aim to teach or train users in a simulated real-world situation through a game, and further allow users to interact with these environments in order to gain a

Table 1
Stressors for vigilance and attention tasks (adapted from Staal, 2004).

Stressor	Impact
Fatigue and sleep deprivation	decrements in vigilance and performance Baranski et al. (2002); Kujawski et al. (2018); increased errors of omission
Time pressure and workload	more errors, poor performance van Galen and van Huygevoort (2000); Wickens et al. (1993); increased errors of commission
Heat	diminished vigilance Pepler (1958): increased errors of omission
Noise	decrements in attention tasks and decreases in reaction times and performance Kjellberg (1990): increased errors of commission

better understanding of the situation (Sorace et al., 2018).

2.3. Serious games for training and decision making

Serious games are increasingly applied in a range of areas and disciplines. They typically offer interactivity coupled with immersive experiences in order to engage people in tasks and activities that are not necessarily considered fun. As such, their application in education and training market has ever been growing over the past decade. Specifically, there are many studies into the positive impact of serious games in training and education. Connolly et al. (2012) reported empirical evidence about their impact to learning and engagement, as well as their benefits to knowledge acquisition and motivation. Similarly, Papaioannou et al. (2016) demonstrated how serious games can be used to modify behaviour and effectively train users in reducing energy consumption. Spyridonis and Daylamani-Zad (2019); Spyridonis et al. (2017) developed GATE, a serious game to train designers about web accessibility guidelines. Along the same lines, Katsaounidou et al. (2019) employed a serious game to help users learn and decide on bogus content in news.

In fact, improving decision making through serious games has long been the focus of past research work. Flood et al. (2018) reviewed serious games that have been used to improve decision making for climate change applications. Serious games have also been effectively used to train the decision making behaviour of groups (Linehan et al., 2009). Johnsen et al. (2016) used a serious game to help nursing students practice their decision making skills, whereas Al Osman et al. (2016), Carlier et al. (2020) and Holz et al. Holz et al. (2018) employed serious games for stress management and awareness. Serious games have therefore the capacity to contribute towards better training in various settings and scenarios and it was found that use of game mechanics helps increase participation in online training by 61% (Halan et al., 2010).

Despite strong evidence for the benefits of serious games, there are limitations to their use. There have been concerns that serious games created in the domain of learning difficulties and autism disorder are designed and developed for high-functioning individuals and therefore their clinical validation does not meet the evidence-based medicine standards (Grossard et al., 2017). In educational games, there are concerns over potential conflicts between intended learning outcomes and game objectives (Frederik et al., 2010; Mitchell and Savill-Smith, 2004). These are further highlighted in Daylamani Zad et al. (2014); Daylamani-Zad et al. (2016) which identifies the need for a balance between how close a task in game environment should be to the real-world scenario. If the task in the game and the mechanics for it are too close the game can become boring, whilst if they are too far apart the game will loose its efficiency.

Accordingly, building on the benefits reported above, this work presents a serious game which aims to simulate a stressful situation for firefighters that allows a player to train their decision making skills through the Stress Exposure Training approach identified earlier. This game is designed with consideration of the limitations of serious games where we aimed to create a balance between the game and the simulated scenario, similar to the approach presented in Spyridonis and Daylamani-Zad (2019), by presenting a scenario that represents the real-world but provides extra cues, rewards, help and a soft User Interface (UI).

2.4. Game design frameworks

A number of game design frameworks have been reported in the literature (O'Shea and Freeman, 2019) towards the development of games, including serious games. However, it is commonly accepted that there is no universal formula for creating a game, as it largely depends on the task and goals for each individual project. For instance, the Bartle Taxonomy Bartle (1996) and the Engines of Play (VandenBerghe, 2014) frameworks mostly focus on understanding player characteristics and motivations with limited consideration to the game context and purpose. Accordingly, this work will be based on Lu-Lu game design framework (Daylamani Zad et al., 2014; Daylamani-Zad et al., 2016), as it specifically addresses decision making games. Lu-Lu framework was designed for collaborative decision making games, which suggests two dimensions to a serious game; the Ludic dimension which is the entertaining dimension of the game and the Lusory dimension which is the serious purpose behind the game. Lu-Lu identifies that in a successful serious game, there is a balance between the two dimensions influencing each other so that the serious aim is pursued without negatively impacting the entertainment aspect. The Lusory dimension consists of a Goal and Means to achieve the goal, Efficiency of achieving the goal, and Complexity of the system. The Ludic dimension consists of game Mechanics, a Story, Technology and Aesthetics. The above framework and its dimensions will be used towards the design of our serious game.

3. Design and implementation

This section presents the detailed design of the serious game, eXtricate, using the Lu-Lu framework and how vigilance stressors (Table 1) are mapped to game stressors in order to simulate a stressful situation for participants.

As suggested in Lu-Lu, the closer the game setting is to the real-world scenario, the easier it will be to achieve the Lusory goal. Hence, the chosen scenario is to help evacuate a number of civilians from a burning building. The participants are unable to move without a player's assistance. The **goal** of the game is to train the firefighters in making decisions under stress. This goal has been implemented using an evacuation mechanic, where a player is required to evacuate victims from a burning building. The **means** for this goal have been implemented as a first person player which would closely resemble the experience of the firefighters. The **aesthetics** of the game need to also include mission information and potential guidance on the screen to help a player progress through the game. The player would be required to choose paths based on the information provided to them about the victims' health and locations. Finally vigilance stressors are implemented both in the story and aesthetics of the game. These are summarised as the framework in Table 2.

3.1. Scenario and environment

The player is presented with the information about victims during a mission briefing which includes their vital stats and location in the burning building. The player then has a limited time of two minutes, indicated via a timer, to attempt to save as many victims as possible.

The player would need to enter the burning building, and then locate and save the victims. Inside the building, there are smoke, flames and obstacles. The player also has health and should be wearing a mask to be able to breathe in the heavy smoke. The mask does warp their vision slightly. Victims are indicated on a mini-map and highlighted in the environment, using a shader developed using Unity's ShaderGraph so that a player can focus on the goal of the game. Each victim has a

Table 2
Mapping the design to Lu-Lu framework.

		Ludic			
		Mechanics	Story	Technology	Aesthetics
Lusory	Goal	Evacuation	Burning building	–	Mission UI
	Means	Movement	Limited life	–	Simulated realism
	Efficiency	–	Path and victim	PC	Vigilance stressors
	Complexity	–	Vigilance stressors	PC	–

different level of vitality and therefore different time to live. The player needs to analyse the situation and save the victims in an optimal order, in order to save the most number of victims they can.

In order to evaluate player performance in decision making under stress, we use a similar approach to Daylamani Zad et al. (2014); Graafland et al. (2014) who record a player's performance in decision making tasks by using the player's score and how fast they have achieved it. To incorporate this into the game, total time taken and the number of victims saved were used as indicators of a player's performance.

3.2. Implemented stressors

We previously discussed that firefighters are often faced with a number of stressors relevant to vigilance situations. The research presented in LeBlanc et al. (2012); Ponder et al. (2003) usefully aligns decision making stressors with vigilance stressors, which can be summarised as:

1. Pace: Time pressure and high tempo music are considered to induce stress.
2. Emotional attachment to the decision: Gravity of the decision, life or death situations or when the player cares about the consequences of the decision.
3. Rewards and punishment: These could be both real or anticipated/perceived.
4. Information overload: Too much information can cause stress when making decisions.
5. Sensory overload: both auditory and visual.
6. Partially visible environment: Incomplete information for making the decision.

Accordingly, Fig. 1 presents the mapping of the above stressors, as they are grouped for the design of the game, to game mechanics suitable to the aforementioned scenario. Table 3 further presents a description of how each mechanic is implemented into the game. Each stressor is implemented using a mechanic which would fit well within a realistic simulation in order to increase immersion and provide a close to real-world experience. Whilst this approach increases the Complexity of the Lusory dimension, it also increases the Efficiency of the serious game.

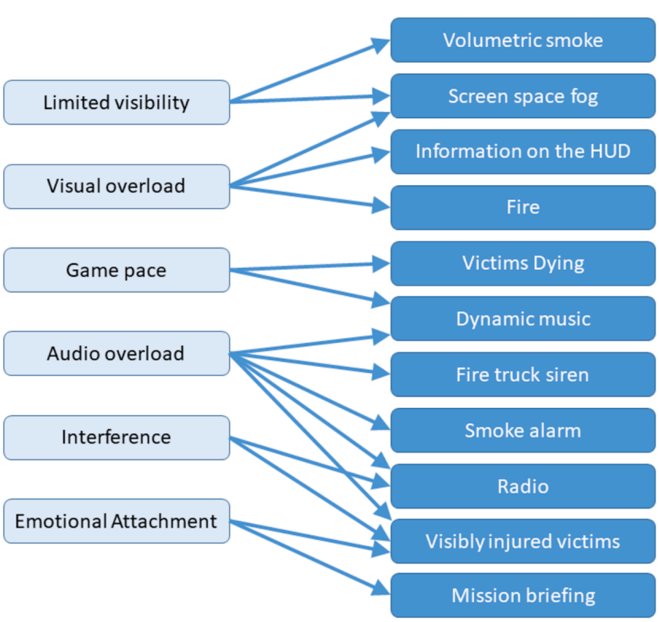

Fig. 1. Mapping stressors to mechanics in game, expanding the proposed framework.

Table 3
Proposed framework: stress inducing mechanics and their descriptions.

Mechanic	Description
Dynamic music	Music changes based on the location of the player. The tempo is also adjusted based on the time left on the timer.
Fire	Helps with realism as well as obscuring vision. The false sense of light and heat is also considered to induce stress.
Fire truck siren	Constant siren in the distance adds to the auditory overload.
Information on the HUD	Information such as victim's heart rate, radar, player health, timer and various animations are used to overwhelm the player. The animations include; pulsing image and heart rate pulse for each living victim, and pulsing victim locations on mini-map.
Mission briefing	The briefing provides some background and information regarding the victims, the layout and the gravitas of the task at hand.
Radio	The player is notified of events and the progress of the mission. The game encourages (rushes) the player with prompts to hasten the player.
Victims dying	One victim cannot be saved; this provides a sense of instability and also brings gravitas to the player decisions.
Smoke alarm	This alarm inside the building can be heard through out the game scenario.
Visibly injured victims	The victims are injured and they can be heard crying for help. There are also prompts for immediate help rather than evacuation.
Volumetric smoke & Screen space fog	Smoke is used to reduce visibility of objects closer to the player, whilst fog is used to obscure farther objects.

3.3. Implementation

The game, eXtricate, was implemented using Unity game engine and C#. It is aimed to work on average PCs so that it is accessible in most places. It is designed to be played using a mouse and a keyboard. It uses low poly assets to increase performance.

3.4. Game flow

As previously mentioned, the game setting is in a burning building. At start, a player is equipped with an audio-visual mission briefing which explains the scenario at hand. The game starts with the player in a fire truck, being driven to location to provide immersion and build emotional attachment. The mission briefing explains that there is a burning building and there are victims inside, as well as displays where the victims are located. The victims are rated on a Risk scale where the higher the number the closer the victim is to death. The goal is to enter the building and save as many victims in as little time as possible. Fig. 2 presents a screenshot of the mission briefing with victims information and risk scale values.

Once the player has analysed the mission brief, they can leave the truck. As soon as they leave the truck, a timer starts counting and the music changes. The timer on the Heads-up Display (HUD) indicates time left until the game is over. Victims are spread throughout the level equivalent to the map shown in the mission brief. Fig. 3 illustrates a top view of the level, identifying the positions or locations of the victims.

Fig. 4 shows the scene from a player's perspective. As can be seen, fire, smoke and fog have been used with added post-processing in order to create an immersive and realistic environment with limited visibility and added stressors of fire and heat.

To prevent the game from becoming a puzzle game and rather focus on the goal of deciding which victim to save next, each victim is highlighted through the smoke. The player moves through fire and smoke, implemented using Unity's particle system, to find victims that are injured and carry them back to the starting point of the game where they

Fig. 2. Mission briefing which shows the victims, their location and their risk scale values. The briefing includes pictures and some description in order to build emotional attachment.

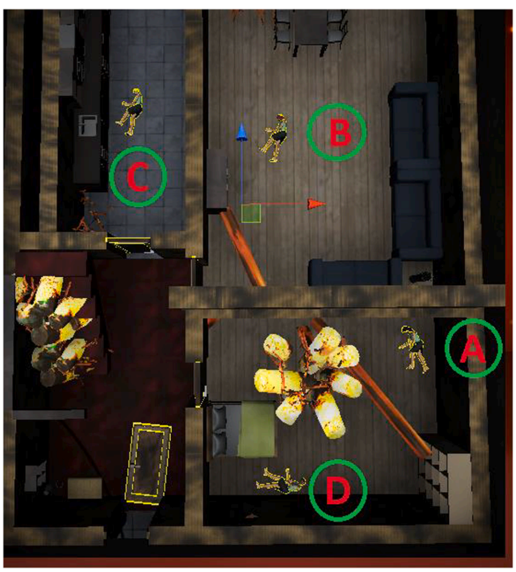

Fig. 3. Victim positions inside the level. These are similar to the locations provided in the mission briefing.

Fig. 4. Fire and smoke incorporated into the scene. These are highlighted further using post-processing. These effects are aimed to reduce visibility.

are placed in a safe spot. Some victims cry for help, one more than the others in order to apply social pressure. The player then returns into the building to save the next victim, and this process is repeated until all victims have been saved, the timer has run out, all victims died, or the player dies. Whilst performing these tasks, a radio attempts to further stress the player by hassling him through the entire performance with comments such as “3 Victims Left!” or “Hurry!”. Fig. 5 demonstrates the user interface element that shows the current victims, their health and their vital stats. This feature reinforces empathy with the victims to increase the gravitas of the decisions. The heartbeat and flashing of victims’ figures as their health drops further contributes to audio-visual overload and time pressure stressors.

4. User evaluation

In order to validate the ability of the developed game to A) induce stress and B) improve decision making performance, an experiment was setup. The experiment involved participants playing the game described in Section 3. The experiment was designed to have two layers. In Layer 1 the participants’ stress levels were self-reported using the STAI-S scale of the State-Trait Anxiety Inventory for Adults (STAI) (Spielberger, 1983b) before and after experiencing the game. The STAI-S scale is typically used to report how participants feel at a particular moment in time and can be used to determine the actual levels of anxiety intensity induced by stressful procedures. Accordingly, we hypothesise that if participants’ anxiety scores increase as a result of using the game, then stress at this particular moment in time has been successfully induced (Spielberger, 1983a). In Layer 2 the participants’ stress level was captured using physiological measurements, namely galvanic skin response (GSR) and heart rate (HR), by recording these before, during and after experiencing the game. Fig. 6 illustrates the steps and layers in the experiment design.

4.1. Physiological measurements

Real-time user physiological responses are a valuable external information source which can be captured directly from the user without a conscious effort from them. They allow for a less biased measurement of changes in the users’ affective state. Affective state is made up of two dimensions: *valence* and *arousal*. Valence is defined as the level of pleasantness the user feels toward a specific stimulus, which ranges in a

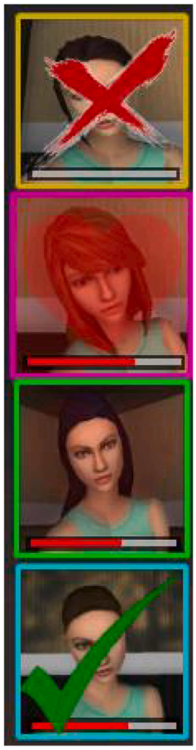

Fig. 5. Picture, health and vital stats of the victims displayed on the UI.

continuum from positive to negative. Arousal, or intensity, is the level of autonomic activation that an emotion elicited by a specific stimulus is felt (Bestelmeyer et al., 2017; Lin et al., 2020). With the technological advances and the rise of the Internet of Things (IoT), physiological response sensors are widely accessible, affordable and more versatile in regards to how they can capture the physiological data.

In this experiment GSR and HR were the physiological responses recorded. GSR, which measures the electrical conductivity of the skin, is a function of the amount of sweat produced by the eccrine glands located in the hands and feet. GSR is believed to have a linear correlation with the arousal dimension. HR acceleration and deceleration has been shown to be an indicator of valence where negative valence is signified by a greater increase in HR than positive valence (Money and Agius, 2010). For the measurement two sensors; Grove - GSR Sensor (Zuo, 2020) and Grove - Finger-clip Heart Rate Sensor with shell Zuo (2022) connected to Raspberry Pi 3 were used.

4.1.1. Method

As mentioned previously, HR and GSR are bidirectional. In addition, the rise and fall of both HR and GSR, their intensity and their fluctuations can differ from person to person (Garnacho-Castaño et al., 2015). Therefore the raw data itself cannot always be comparable. Furthermore, not all fluctuations in HR or GSR are significant enough to be included in the analysis and some fluctuations could be due to sensor inaccuracies. These and the sheer amount of data points can make the accurate analysis of physiological responses difficult. Therefore, it is vital to establish a normalised dataset that is ranked based on significance which would allow for comparable and accurate analysis of the responses.

We have followed a similar approach to Money and Agius (2010) in order to create high-low data which would allow us to cater for the bidirectional nature of the HR and GSR. We adopted a default standardised sampling rate of 8Hz to standardise the data from the sensors and to synchronise the observations so that observation time stamps correspond for both measurements. According to Money and Agius (2010) 8Hz provides sufficient detail. The standardised data is then subjected to moving window average and detrending calculations. This would enable construction of initial percentile rank (*IP*) data which can be converted to high-low data.

We apply a moving window average calculation to HR in order to construct *S* Value, presented in Eq. (1). In this equation, *srr* is the frequency of the standardised physiological response data observations (Hz), *mgsal* is the minimum game sequence action length as performed by a player (seconds). $\mathrm{HR\_}S_t$ is the constructed HR value and *t* represents the point in time from which the moving average is calculated. *T* stands for the final point in time from which *t* is calculated. V_{t-i} represents the actual value of the HR signal at the time $t-i$.

$$\mathrm{HR\_}S_t = \frac{1}{srr \times mgsal} \sum_{i=1}^{srr \times mgsal} V_{t-i} \qquad (1)$$
$$t = srr \times mgsal, srr \times mgsal + 1, \ldots, T$$

The GSR baseline varies significantly during the experimental sessions (Slater et al., 2006), therefore we need to treat the GSR data differently. $\mathrm{GSR\_}S_t$, the constructed *S* value for GSR which is presented in Eq. (2), also reflects players' minimum game sequence action length. Similarly, the moving window is calculated as $srr \times mgsal$. In this approach we identify the value of the signal immediately before a rise within an appropriately sized moving window. Therefore, this method allows for evaluating fluctuations in GSR regardless of baseline variations. $\mathrm{GSR\_}S_t$ is calculated with the assumption that $\min V_i$ for time point θ occurs before $\max V_i$ for the same time point. Otherwise, $\mathrm{GSR\_}S_t$ is set to zero.

$$\mathrm{GSR\_}S_t = \max_{i=t}^{t-((srr \times mgsal)-1)} V_i - \min_{i=t}^{t-((srr \times mgsal)-1)} V_i \qquad (2)$$
$$t = srr \times mgsal, srr \times mgsal + 1, \ldots, T$$

We calculate initial percentile rank (IP) values for HR so as to

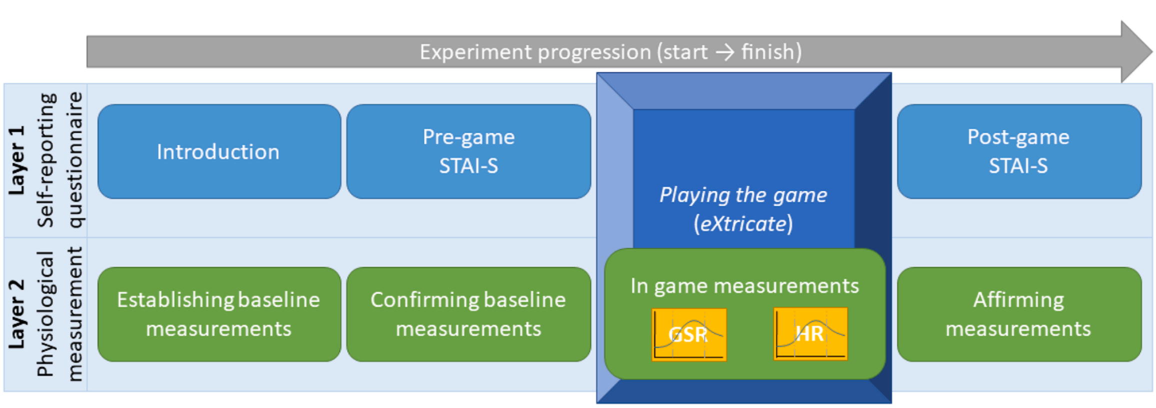

Fig. 6. User evaluation setup: using the game, questionnaire and physiological measurements.

standardise and normalise S values for HR, establishing a measure of significance for each value in the collected sample. The percentile rank calculation ensures that the response values for HR are directly comparable and reflect the distribution of the sample, even for skewed data. Eq. (3) represents the calculation of initial percentile rank for HR, HR_IP_t, where HR_S is the whole sample, E_S represents the group of S values within the whole sample that are equal to HR_S_t and L_S is the group of S values within the whole sample that are less than HR_S_t.

$$\begin{aligned} HR\_IP_t &= \frac{|E_{HR\_S_t}| + |L_{HR\_S_t}|}{|HR\_S|} \\ E_S &= \{s : s \in HR\_S \wedge s = HR\_S_t\} \\ L_S &= \{s : s \in HR\_S \wedge s < HR\_S_t\} \end{aligned} \tag{3}$$

The IP values are representatives of bidirectional fluctuations in player responses. We split the IP values into high and low datasets. The high values are considered as IP values ≥ 0.5 (Eq. (4)) and low values are considered as IP values ≤ 0.5 (Eq. (5)). Values in the low dataset are then inverted so that their significance is expressed on a similar scale as the high values on a range of (0–1), where 1 is most significant and 0 is least significant. These two high and low values are then combined in Eq. (6) to create a unidirectional representation of the player's HR responses, HR_UD_t.

$$HR\_High_t = \begin{cases} HR\_IP_t & HR\_IP_t \geq 0.5 \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

$$HR\_Low_t = \begin{cases} 1 - HR\_IP_t & HR\_IP_t \leq 0.5 \\ 0 & \text{otherwise} \end{cases} \tag{5}$$

$$HR\_UD_t = HR\_Low_t + HR\_High_t \tag{6}$$

In order to enable efficient comparison of values, we need to re-standardize the measures. This is achieved through constructing percentile rank values for the respective unidirectional datasets. Eqs. (7) and (8) represent calculating the percentile rank values for HR and GSR respectively. In Eq. (7), HR_UD represents the full unidirectional sample, E_{UD} represents the group of HR_UD values within the whole sample that are equal to UD_t and L_{UD} is the group of HR_UD values within the whole sample that are less than UD_t. As GSR is naturally presented as a unidirectional measure, the results of Eq. (2) are converted to UDP values by applying the percentile rank calculation on the GSR_S values as presented in Eq. (8). For both cases, the response value is considered to be more significant when the UDP value is higher.

$$\begin{aligned} HR\_UDP_t &= \frac{|E_{UD}| + |L_{UD}|}{|HR\_UD|} \\ E_{UD} &= \{u : u \in HR\_UD \wedge u = HR\_UD_t\} \\ L_{UD} &= \{u : u \in HR\_UD \wedge u < HR\_UD_t\} \end{aligned} \tag{7}$$

$$\begin{aligned} GSR\_UDP_t &= \frac{|E_{GSR}\_S| + |L_{GSR}\_S|}{|GSR\_S|} \\ E_{GSR}\_S &= \{g : g \in GSR\_S \wedge g = GSR\_S_t\} \\ L_{GSR}\_S &= \{g : g \in GSR\_S \wedge g < GSR\_S_t\} \end{aligned} \tag{8}$$

Finally, the standardized UDP formatted values of the two physiological responses are combined to produce a unified player response measure, UPRM, which combined the two unidirectional values as presented in Eq. (9). A final percentile rank calculation is applied to the UPRM, Eq. (10) to standardize the responses and assign each UPRM value a significance between 0 and 1. This enables allocating a unique percentile rank to each UPRM value which reflects the significance of each UPRM in percentile rank format (SUPRMP).

$$UPRM_t = GSR\_UDP_t + HR\_UDP_t \tag{9}$$

$$\begin{aligned} SUPRMP_t &= \frac{|E_{UPRM}| + |L_{UPRM}|}{|UPRM|} \\ E_{UPRM} &= \{x : x \in UPRM \wedge x = UPRM_t\} \\ L_{UPRM} &= \{x : x \in UPRM \wedge x < UPRM_t\} \end{aligned} \tag{10}$$

4.2. Participants

The participants were recruited through the authors' contacts and they consisted of a random population, which did not include firefighters. The experiment included 25 participants, which were all unpaid volunteers, aged between 18 and 40 ($M = 27.68$, $\sigma = 6.11$) and included 14 males and 11 females. All participants had experience in playing games, whilst 15 out of 25 of participants played games regularly.

4.3. Procedure

Ethics approval was granted by the University of Greenwich Research Ethics Committee. Upon arrival each participant was seated at a PC with the game pre-loaded and would put on the glove with GSR and HR sensors. The measurements start at this point to establish an initial baseline. Then, the participants were given a consent form at the start which provided information about the purpose of the experiment and the process involved, whilst during this time the baseline GSR and HR were being confirmed. This was followed by a pre-experiment self-assessment using STAI-S, and whilst the participant was filling the questionnaire, the baseline was confirmed.These confirmation data are used to establish if the pre-experiment information and self-assessment have had any impact on the participants' HR and GSR readings. Once the questionnaire was filled, each participant would play three levels in the game. The levels are very similar in their abstract layout, but look different enough for the player not to realise this. The levels are separate scenes which would allow for making aesthetic changes (i.e. entering an apartment as opposed to a house) that would be distinguishing enough for the player. The starting menu of the game provides participants with a description of the scenario and the effects and emotions they may experience. Participants are instructed to attempt to block these emotions through proper breathing and focus on the goal as part of Phase 1 and 2 of the SET (Driskell et al., 2008). The experiment task involved participants trying to save as many victims in as little time as possible in a burning building, in accordance with the game scenario. The physiological measurements are continuously recorded during gameplay. Once the task was finished, the participants were asked to re-assess using the post-experiment STAI-S. The physiological responses during this stage are used to further confirm the heightened stress in comparison to the baseline. The full experiment session lasted approximately 25–45 minutes depending on the participant.

4.4. Results: stress induction; self-assessed

The pre-experiment and post-experiment results of the self-assessment questionnaire for STAI-S were collated and analysed. The pre-experiment STAI-S score had a mean of 36.96 whilst the post-experiment results had a mean of 43.68 which shows a clear increase in the stress levels through playing our game. Table 4 summarises the statistical analysis of the pre-experiment and post-experiment results.

Table 4
Mean, Standard Deviation and Cronbach's alpha, minimum and maximum values for pre-experiment and post-experiment STAI-S questionnaire.

	Mean	Std Dev	Cronbach's alpha	min	max
Pre-expt	36.96	10.93	0.91	57	21
Post-expt	43.68	10.36	0.89	61	20

A Wilcoxon matched pairs signed-rank test was additionally performed to determine whether there is a significant difference between the two questionnaires. The results demonstrated that the difference is statistically significant ($Z = -3.491$, $p = 0.000$), and therefore, the game has managed to increase stress levels in the participants, as anticipated. Hence, the stressors used in the game have successfully managed to achieve their aim. A further power analysis was preformed on the results to assess the probability of correctly rejecting the null hypothesis (i.e. the game has not managed to increase stress levels). The power analysis demonstrated a high probability ($Pr = 1$) for correctly rejecting the null hypothesis, therefore demonstrating the sample size has been sufficiently significant.

4.5. Results: stress induction; physiological measurements

The results of the physiological measurements (HR and GSR) gathered during the experiment were collected, standardised and analysed using the method defined in Section 4.1.1. The results show a clear increase in the SUPRMP, which we interpret as stress levels, of players as they went through the experiment, confirming the results from the self-assessment. The physiological measures are established at each stage of the experiment *Introduction, Pre-game STAI-S, Playing the game, Post-game STAI-S*. The time during play has been divided into five timepoints based on the duration of the timer; *timer=2.00* (start of game), *timer=1.30, timer=1.00, timer=0:30* and *timer=0.00* (end of game). These make eight timepoints (observation points) to demonstrate the differences in the physiological measurements. Fig. 7 presents the SUPRMP (stress level) for each participant and their respective trendline. Fig. 8 presents the average SUPRMP (stress level) across all participants at each of the eight observation points. The values between observation point 2.00 (Start) and 0.00 (End) are the average of the SUPPRMP values across the three levels which players have played. The figures present the average across the three levels for better clarity of presentation and to enable a more accurate calculation of the trendline.

As observable in these two figures, the SUPRMP (stress level) between introduction and pre-game self-assessment shows a very small increase which is attributed to the excitement of starting the experiment. However, once the game has started, the timer starts counting down and all the visual and auditory cues are applied, there is a sharp increase in the SUPRMP (timer at 2:00), the increase continues as the timer counts down towards the end (timer at 0:00). There is not much difference between observation points 0:30 and 0:00 as most participants have reached maximum (≥ 0.99) levels. There are a few exceptions such as P9 who does not reach 0.83 at the highest level of SUPRMP (stress level). P1 also has a much slower buildup of SUPRMP (stress level) compared to other participants. There is also a slight drop in SUPRMP (stress level) at the post-game self-assessment which is attributed to the relief of having finished the game and lack of in-game stress cues (auditory and visual).

A Wilcoxon matched pairs signed-rank test was performed to determine whether the differences between the SUPRMP (stress level) at consecutive observation points are statistically significant, its results are presented in Table 5. According to this, the results and differences between various observation points are statistically significant ($p < 0.50$) except for the difference between timer = 0:30 and end of game (timer=0:00). As mentioned previously the difference between these two were negligible and for most participants did not present any difference as most had already reached their maximum SUPRMP (stress level) at 0:30. Based on these results, it is possible to conclude that eXtricate has been able to successfully induce stress in participants. This has been confirmed both through self-assessment and physiological measurements and is statistically significant.

4.6. Results: performance

The impact of the game has been also evaluated based on the decision making performance of the participants. As demonstrated in Fig. 9, participants' performance in decision making improved over three attempts. Specifically, participants increased their score by an average of 22.12 between the first and second attempt, and by the third attempt, the scores were improved by an average of 7.44. This shows a sharp increase between the first and second attempts which is not matched between the second and third attempt. This can be explained as the participants are still understanding the game and environment in the first attempt, and therefore, the second attempt shows a sharper increase

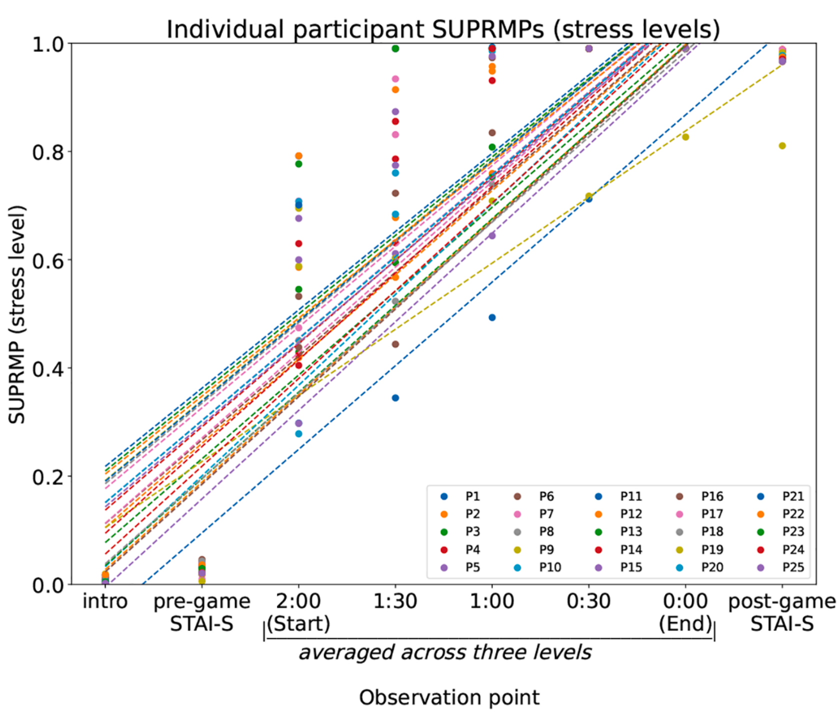

Fig. 7. Stress level (SUPRMP) for each individual participant per observation point with trend lines. The values between 2.00 (Start) and 0.00 (End), during game play, are averaged across the three levels.

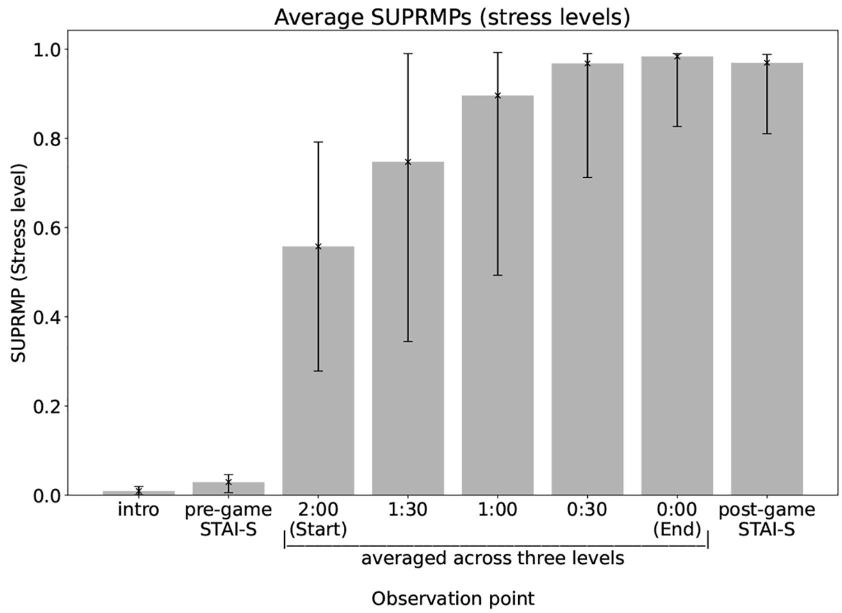

Fig. 8. The average stress level (SUPRMP) per observation point.The values between 2.00 (Start) and 0.00 (End), during game play, are averaged across the three levels.

Table 5
Wilcoxon matched pairs signed-rank test for SUPRMP (stress level) at consecutive observation points.

	Mean	Std Dev	*Z*	*p*
intro - pre-game	– 0.020	0.009	– 4.372	0.000
pre-game - 2:00 (Start)	– 0.52	0.161	– 4.372	0.000
2:00 (Start) - 1:30	– 0.18	0.121	– 4.372	0.000
1:30–1:00	– 0.14	0.112	– 4.015	0.000
1:00–0:30	– 0.071	0.107	– 3.351	0.001
0:30–0:00 (End)	– 0.015	0.0588	– 1.342	0.180
0:00 (End) - post-game	0.014	0.008	– 4.372	0.000

statistically insignificant at the 5% level.

in performance. The participants' behaviour throughout the levels was consistent. Specifically, participants tended to visit the room that was closest to their last visited room regardless of the risk values in the brief.

Fig. 10 presents the distribution of victim saves. As the majority of the participants visited room "A" first, victim "C" in room "C" is already dead by the time they get back inside the building. Participants seem to accept this behaviour and decided to skip room "C" in later attempts as well. These findings are in line with previous work showing that fast-paced action games can improve a number of individual traits and skills, including spatial cognition, reaction time, attention, and aspects of executive functioning (Bavelier et al., 2012). Of course, in this research we are not aiming to improve performance and therefore whilst the results are promising, they are not definitive.

5. Concluding discussion

In this paper we presented a novel serious game that was developed to assist towards efforts focusing on training for fire evacuation and making better decisions under stressful vigilance situations. An empirical experiment was reported which investigated its ability to initially increase stress levels and examine whether participant decision making

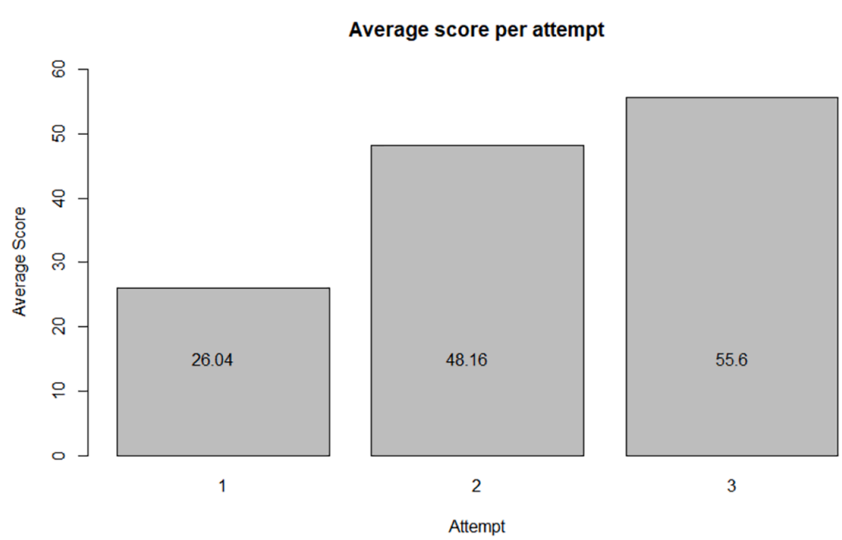

Fig. 9. The average score for each attempt shows an upward increase.

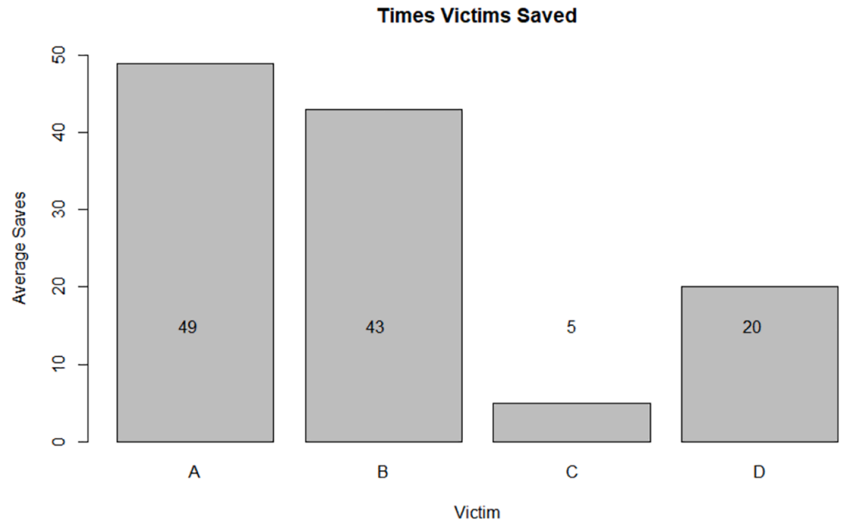

Fig. 10. The number of times victims were saved during the experiments.

performance would be improved under stress. The results indicated that our serious game successfully managed to increase participants stress levels through its gameplay and implemented scenario (Tables 4 and 5, Figs. 7 and 8). These results are confirmed both through self-assessment and collected physiological measurements (HR and GSR). Accordingly, participants' decision making performance improved through repetitive exposure to the game scenario (Fig. 9) which is in line with past research discussing that stressors that are repeated have been associated with changes in decision making-related brain regions (McEwen, 2007). An interesting finding that also arose from our results is that participants tended to visit the room that was closest to their last visited room regardless of the risk values in the briefing (Fig. 10). This demonstrated a decision making behaviour that is consistent with past work on the mere-exposure effect (Zajonc, 2001) which indicates that people tend to develop a preference for things merely because they are familiar with them.

A number of contributions arose from this work. We demonstrated that the implemented decision making stressors have proven to successfully induce stress to the participants. Following Shafer's stress management model (Schafer, 1996), this can have an important implication to the efforts towards studying strengths that enable firefighters to handle stress. Our user experiment also revealed that familiarity with the search area (e.g. layout of a building) is an important consideration to participants and could be a particularly helpful finding for firefighters when making rescue decisions. This is in line with previous research showing that exposure to such stressors and changes in the surroundings could lead to firefighter disorientation and inability to perform tasks (Chammem et al., 2012). Work by Routley further demonstrated that firefighters can be hindered by low visibility and unfamiliarity with the building layout (Routley, 1995). Accordingly, potential applications of these findings include the design and implementation of informed interventions for monitoring of emergency personnel stress and decision making, as well as the improvement of communication methods used in emergency situations which can be affected due to the aforementioned factors. Finally, we found that simulating decision making stressors through a game could be facilitated through certain game mechanics (Fig. 1) which have shown to be effective for both inducing stress, as well as for helping to improve decision making performance for participants. The findings can be of particular importance to practitioners developing games for future similar efforts.

Our findings present certain limitations. We acknowledge that the small number of participants may have an impact on the generalization of our findings. Additionally, we also acknowledge that participants were not firefighters themselves, however, their participation at this stage of our work is very useful as they offered significant insights in stressful decision making and their contributions could be used as a point of reference for future efforts. Finally, we appreciate that we used only two physiological responses (HR and GSR). Employing additional physiological measures such as Electroencephalography (EEG), Respiration sensors (RIP) and Facial emotion analysis could add further insights, such as real-time effects of the stress cues on brain behaviour with EEG, changes in breathing patterns with RIP and mapping emotional cues of facial stress. Accordingly, our findings present a main avenue for future work which includes a further study to address the effectiveness of our game with firefighters. Overall, this work can contribute to ongoing efforts to improve decision making of emergency personnel in situations of high vigilance.

CRediT authorship contribution statement

Damon Daylamani-Zad: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration. **Fotios Spyridonis:** Methodology, Validation, Formal analysis, Investigation, Resources, Writing – original draft, Writing – review & editing, Project administration. **Kamal Al-Khafaaji:** Conceptualization, Software, Validation, Data curation, Writing – original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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