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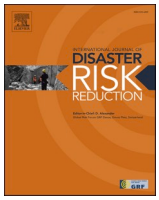

Improving bushfire preparedness through the use of virtual reality

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1. Introduction

The Australian Black Summer fires (2019–2020) burnt an estimated 18.6 million hectares, destroyed more than 5900 structures and killed 34 people [1] Unfortunately, most climate change predictions suggest the frequency and intensity of bushfires will increase, making such catastrophic events more common [2–5]. The need for the public to become more informed and more actively engaged in bushfire safety has never been greater. Comprehensive bushfire preparedness considers many factors including understanding bushfire conditions, property exposure, the ability of built structures to withstand exposure, the condition of surrounding property, equipment availability, as well as the physical and emotional preparedness of residents [6]. While public apathy is often blamed for inadequate preparation, the reality is often much more complex and nuanced. The current position of the Australian fire and land management agencies is, "The safest action to protect life is for people to be away from the bushfire or threat of bushfire as early as possible" [7]. However, the reality is many people delay evacuation, and others who feel their home is designed specifically to withstand fire and they are physically prepared to stay and defend their property, neglect to recognise the emotional toll such an experience can cause.

This paper describes a study that used virtual reality to immerse people in a fire situation, challenging their assumptions, testing their knowledge, and questioning their decisions and sense of physical and emotional preparedness. The objectives of the study were to develop and evaluate an immersive virtual reality scenario that (1) engages and educates a diverse audience about bushfire preparation (2) increases knowledge of the triggers that prompt protective actions, and (3) acts as a catalyst for behaviour change. The behaviour change that was targeted was the development of a written bushfire survival plan. This was based on evidence from a Royal Commission into a previous large scale catastrophic fire in Australia that found many residents of bushfire prone areas did not have such plans or had plans that were insufficient [8].

1.1. Meeting the challenge of lack of preparation and decisive actions

The Country Fire Service (CFS), the key organisation mandated with fire suppression, rescue and public education on fire in South Australia, employ a myriad of techniques to educate people about bushfire preparation that are pedagogically well-designed, available in multiple languages and targeted at specific market segments. Yet, there is still a large percentage of people not leaving early, not actively defending and not acting decisively during bushfires [1,9]. It is axiomatic in bushfire education, that many people's bushfire preparation is inadequate. In Australia's Black Saturday fires in Victoria it was found the majority of people who died did not have a comprehensive bushfire survival plan and of the fatalities who chose to stay and defend, only 20% were found to be well-prepared. Of those who did evacuate, under 1% were well prepared with most not knowing when and where to evacuate [8]. Lack of preparation is not a new phenomenon. Records of the number of bushfire fatalities between 1800 and 2008 in Australia show that almost one third of deaths occurred because of late evacuation [10], a

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consequence typical of poor preparation where residents wait until they are directly threatened by bushfire and then decide to leave as a result of stress and fear [11,12]. Encouraging better choices and more decisive actions is critical.

One theoretical framework which predicts the key influencing factors associated with human decision making in response to disasters is the Protective Action Decision Model (PADM) [13]. This theory describes decision-making as a process in which environmental cues (e.g. sight and sound of fire), social cues (e.g. neighbours' evacuation), warning messages and personal characteristics initiate the individuals' pre-decisional processes which in turn shapes three core perceptions of environmental risk, protective action perception, and stakeholder perception. These perceptions lead individuals to make decisions about adopting a protective action [14]. PADM has been used in a variety of bushfire-related studies especially for examining the influential factors on evacuation decisions. Environmental and social cues have often been related to at risk residents' responses to evacuation. For instance, McCaffrey, et al. [15] evaluated the importance of socio-environmental cues and found that residents who delayed evacuation mostly rely on environmental cues. According to McLennan et al. [12] social cues, such as advice from family, friends or neighbours or observation of their actions, often influence behaviour in a bushfire situation. In a study of people impacted by the 2009 Victorian bushfires, McLennan, et al. [16] assert that a high percentage of evacuees based their decision on face to face contact with neighbours.

The effect of receiving official warnings was also found to be an important factor on evacuation decisions [15,17]. The fire danger rating (FDR), one of the Australian bushfire warning systems, predicts the consequences of a probable fire in a region for the following day. It currently comprises of several classifications from 'Low' to 'Catastrophic' (Code Red) and this information is communicated to the public via highway signs, television and radio news and via the websites of fire-protection organisations. Unless a home is specifically designed to withstand fire, residents are advised to leave early any time the FDR is catastrophic or extreme for their region, or when the rating is severe and they are not well prepared. Other warning messages are also used to alert residents about a situation and the recommended way to respond. At the time this research was conducted three distinct warnings could be issued: an advice message notifying people of a risk in the area; a watch and act message which notifies people that a fire is approaching and they need to take action; and an emergency warning message that notifies recipients that they are in danger and need to take immediate action. This information is communicated to the public via a number of means including mobile phone messages, social media, websites and radio. A meta-analysis by McLennan et al. [9] found that receiving warning messages often does not lead to immediate evacuation for residents in bushfire prone areas as they are unsure about the severity of the risk and perceive leaving early as an unnecessary and costly process. An Australian study in New South Wales by Whittaker et al. [18] found residents had a tendency to wait for a confirmation of warning messages before taking protective action and instead used personal observations such as the sight or smell of the fire before acting decisively. While waiting for cues such as visible smoke, embers or flames and the smell of fire, seems common practice, delaying action by waiting for such cues is dangerous [19]. Hence, understanding how people respond to environmental cues is vital in designing targeted fire communication strategies [15].

Many studies have highlighted the effect of gender on protective action decision making [20–24]. Age has also been found to influence decisions. In a study of Victorian Black Saturday bushfires survivors, McLennan, et al. [16] found those residents choosing to stay and defend were slightly older than residents who decided to leave. In a study of Adelaide Hills residents, Bardsley, et al. [2] found residents aged 18–44 were the least prepared and least knowledgeable regarding bushfires.

1.2. The need to increase understanding related to active sheltering

Evidence from the Royal Commission into the Black Saturday fires showed in 70% of death cases, there was no evidence of defence [8]. A total of 69% of deaths occurred while people were sheltering, with the bathroom being the most common location of death, accounting for 27% of fatalities. Bathrooms are poor choices for sheltering in bushfires as they do not have multiple exits and generally have poor visibility [25,26]. A further 22% of people died outside the home and 14% died fleeing in cars or on foot, providing evidence that many people do not recognise the protective value a home has in a bushfire [27]. Whittaker et al. [25] stress the importance of active sheltering as a type of protective action and recommend that further research be conducted to investigate occupants' knowledge, intentions and preparation about active sheltering, especially to understand how people react to protect themselves during actual fires.

1.3. The need to acknowledge both emotional and physical preparedness

Human behaviour in response to bushfires during and after disasters depends on physical and emotional (psychological) preparedness [28,29]. Past research has shown people who have prepared their physical surrounds for a fire are more likely to be associated with those who chose to stay and defend [16,30,31]. According to McLennan et al. [32] those staying to defend their properties were more likely to have plans for active defence if threatened by bushfires. While the importance of physical preparation cannot be overstated, many authors have called for greater attention to the concept of emotional preparation for bushfires [29,33,34]. Emotional preparedness is vital in managing stress, deliberating and acting decisively [28]. The nature of emotional preparation is so context specific and dependent on individual characteristics, that Eriksen and Prior [35] argue traditional risk communication practices are not appropriate. There is a need for a more creative, adaptable and interactive approach to bushfire risk communication.

1.4. The potential of virtual reality

The development of a VR scenario that includes a variety of social and environmental cues could provide improved understanding on how these cues affect peoples' decision making and response to bushfire. VR can facilitate a tangible, relevant experience of a fire in a safe context and the addition of gamification components can enhance engagement. Virtual reality (VR), and in particular, gaming, has the advantage that it is appealing to many young people, who are an important target audience. Studies by McGonigal [36,37] show young adults spend a disproportionately large proportion of their free time immersed in high-tech computer gaming.

Gamification can help to engage people in understanding dynamic contexts, the need for rapid decision-making, and the consequences of decisions [38,39]. The growing availability of commercial head-mounted displays (HMDs) has made VR technology accessible to the general public. Improved user interfaces and a new generation of the HMDs have allowed better quality products with lower prices being used in a range of applications [40]. While entertainment has been a major application, training and education providers are increasingly seeing the benefits of VR [41–43]. Its strength lies in its capacity to enhance learner engagement through realism and interactivity of the learning process [44]. Its training applications include traffic safety [45], emergency evacuation safety [46], safety at construction sites [47], general safety training [48] and fire safety [42,49–55].

This study explores the use of virtual reality as a means to understand how people respond to environmental triggers during imminent bushfire threats. It also aims to evaluate the effectiveness of the "Facing Fire" VR scenario in engaging, educating and initiating behaviour change in relation to bushfire preparation. By placing people in a realistic scenario, the intention was that it would make people more aware of the

importance of pre-planning and contingency plans, the need to actively prepare and patrol their properties, as well as acknowledge the emotional stress induced by such an incident. Ultimately, the goal was that people would choose to develop a written bushfire survival plan.

2. Methodology

2.1. Overview of methods

The Protective Action Decision Model (PADM) and specifically the socio-environmental cues that influence participants' decisions and responses underpinned the design of the "Facing Fire" scenario. Participants were immersed in a compelling narrative that involved the three stages of a fire approaching a home: before the fire arrives, during the fire, and after the fire front has past. The scenario also included four gamified exercises focusing on property preparation, active patrolling and the decision-making process regarding active sheltering. The scenario was developed as two customised, related versions for two groups of residents; one for residents who planned to 'stay and defend' their properties, and the second one for residents who intended to 'wait and see' before acting on a predicted 'severe' fire danger day. Those participants who indicated they would 'leave early" did not participate in this component of the study. The versions of the scenario were identical in terms of the scenes and the type of triggers presented within the VR environment, as well as the gamification components. The only differences involved the wording of specific VR embedded questions. The 'wait and see' cohort were asked about their intention to leave after exposure to each socio-environmental trigger while 'stay and defend' participants were asked about their level of concern about their survival after exposure to the triggers. Therefore, the intended focus of the 'wait and see' version of the scenario was to examine if particular socio-environmental triggers seemed to have a greater influence on their decision to leave than others, while the 'stay and defend' scenario focussed on emotional preparedness and concern about personal safety associated with defending. The scenario was tested among residents of bushfire prone areas in South Australia who were recruited primarily at CFS and other public events.

There were two related but distinct phases to this work: (1) the development of the VR "Facing Fire" scenario and (2) the evaluation of the scenario. An overview of the development phase is presented graphically in Fig. 1 and details of each phase are discussed below.

2.2. Creation of the virtual scenario

Defining the objectives and scope of the project was done in consultation with the South Australian Country Fire Service (CFS) and with consideration to existing resources. To make the scenario more relatable, it was decided to set the context as a typical family home with pets, on a severe weather day. The severe FDR was selected because of a concern from the CFS that while many people are clear on what they would do on a catastrophic or extreme weather day, many have not thought that they should also be evacuating early on a severe rated day if they are not well prepared and their home is not specifically built or designed to withstand a bushfire. Moreover, it provided the opportunity to present a realistic scenario of weather conditions changing rapidly. It was also decided to maximise learning potential that the scenario should incorporate all three phases of a bushfire: (1) before the fire arrives; (2) during the fire; and (3) after the fire front has passed. It was determined two versions of the VR scenario were required; one for residents who planned to 'stay and defend' and a second one for residents who intended to 'wait and see'. As mentioned previously the only difference in these scenarios was the wording of the embedded questions, which needed to reflect the intention of the participants (i.e. those who wanted to 'wait and see' were questioned about when they would take action; and those indicating they would 'stay and defend' were questioned about their level of concern).

The scenario consisted of 17 scenes which incorporated numerous inter-related triggers that were broadly aligned to the socio-environmental cues of the Protective Action Decision Model. The scenes outlined in Table 1 and shows a total of nine major social and environmental cues as triggers presented in sequence during the VR, including all three warning messages that can be provided in a fire and that were likely to influence decision making as well as four gamification exercises.

The aim of studying participants' response to triggers during the VR scenario was twofold: first, to understand the importance of the first six cues (advice message, busy roads, watch and act message, neighbours leaving, visible smoke, and emergency warning) in relation to 'wait and see' cohort's decision to leave; second; to compare level of concern between 'wait and see' and 'stay and defend' cohorts. In general, the focus for both cohorts was to understand the level of concern associated with each trigger and how that single or cumulative effect of triggers manifest in concern for survival or desire to leave. Fig. 2. Depicts three examples of triggers; scenes containing socio-environmental cues of neighbours leaving, visible smoke and emergency warning which are presented within the VR environment. The two versions of the scenario were identical in terms of overall narrative and sequence, as well as the variety of triggers portrayed. While the imagery was identical in the two versions of the scenario, the VR embedded questions were different for the first six triggers out of nine. To gain greater insights into behaviour, the 'wait and see' participants were not actually able to leave within the VR experience when they wanted to but rather were given another scenario (a tree blocking their access route) which looped them back into a need to stay and defend, reinforcing the need for a contingency plan in case you are unable to leave.

It was also determined through consultation with our industry collaborator the SA Country Fire Service, that the creation of a virtual reality experience capable of improving fire preparation, would require six key elements: (1) a clear set of objectives and scope for the scenario (s) that aligned with the goals of the CFS; (2) a realistic narrative so people could relate to the scenario and feel they were really in the disaster; (3) gamification components designed to increase the learning potential of the scenario and enhance the entertainment value and hence engagement; (4) decision-making components designed to make users recognise that a fire is context specific and they need to be prepared to make rapid, logical decisions relevant to the scenario as it unfolds; (5) a duration short enough to encourage use, and allow scalability in public forums; but long enough to incorporate key messages; (6) sufficient twists and intensity to allow people to understand the dynamic nature of fire and the need for contingencies.

2.2.1. Scenario overview and the gamification components

In the beginning of the scenario, a voice over prompts participants to pay attention to the situation that involves a hot day with a 'severe' fire danger rating. It was an outdoor scene where participants could see strong winds and changes in the weather condition. Participants were then exposed to the narrative as the fire approached their home. First, they received a CFS advice message on their mobile phone, warning that a fire is in the area, there is no immediate danger but they should stay up to date in case the situation changes. The next scene, took participants outside where they observed the road was starting to get busy (social cue). Then they received a "Watch and Act" message on their mobile phone explaining that there is a heightened level of threat, that conditions are changing and they should take action now to protect themselves and their families. Then, during the first gamification component, they started looking for items they could move to make outside of the house safer. In the next scene, they saw their neighbours who they thought were planning to 'stay and defend' are loading the car to leave (social cue). After seeing visible smoke in the proximity of their property (environmental cue), the scenario took them outside again to look for items that would help them defend their property (the second gamification component). Then, they received a CFS emergency warning on

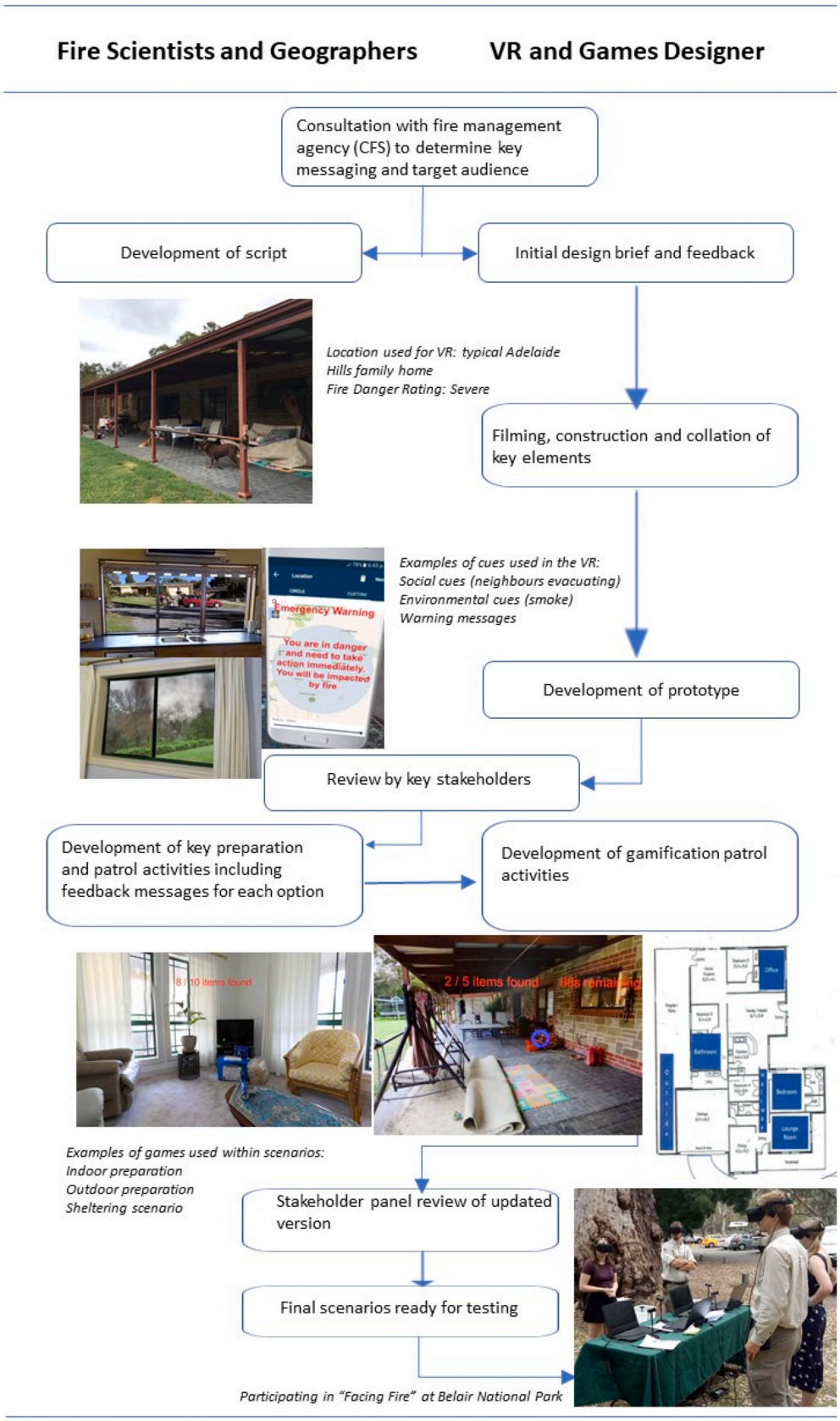

Fig. 1. Construction of the 'Facing Fire" Virtual landscape – key stages in the interdisciplinary design process.

Table 1
Sequence of scenes and the purpose of each scene in the scenario.

Scene No.	Purpose	Trigger	Relation to PADM
1	Introductory scene		
2	Providing the context of the scenario		
3	To measure the effect of the trigger on behavioural response (decision to leave or concern about survival)	CFS advice message	Warning message
4	To measure the effect of the trigger on behavioural response (decision to leave or concern about survival)	Busy roads	Social cue
5	To measure the effect of the trigger on behavioural response (decision to leave or concern about survival)	Watch and act message	Warning message
6	Gamification component 1: Feedback based exercise to measure ability in locating dangerous items around the building		
7	To measure the effect of the trigger on behavioural response (decision to leave or concern about survival)	Neighbours leaving	Social cue
8	To measure the effect of the trigger on behavioural response (decision to leave or concern about survival)	Visible smoke	Environmental cue
9	Gamification component 2: Feedback based exercise to measure ability in locating useful items around the building		
10	To measure the effect of the trigger on behavioural response (decision to leave or concern about survival)	CFS emergency warning	Warning message
11	To measure the effect of the trigger on behavioural response (concern about survival)	Flames and amber	Environmental cue
12	To measure the effect of the trigger on behavioural response (concern about survival)	Communication channel down	Information source
13	Gamification component 3: Feedback based exercise to measure ability in locating useful items inside the property		
14	To measure the effect of the trigger on behavioural response (concern about survival)	Power has gone out	Information source
15	Decision Making Exercise: Sheltering exercise to measure ability to shelter in a safe place		
16	Fire has passed_ advice on recovery after a bushfire		
17	Final remarks		

their phone advising them that they are in danger, will be impacted by fire and need to take action immediately followed by a scene in which they witnessed flames and embers (environmental cue). Then their communication channels went down. The third gamification activity involved preparing participants in a preparation activity for the fire inside the property. After smoke begins to enter the home and fire alarms sound, they could no longer use their phones and the home became dark. The last gamification activity was to identify a safer place to shelter in the house. The fire then passed the house and a voice over explained procedures to embark on once the fire passes and concludes with encouraging participants to prepare a written bushfire survival plan and providing the CFS website as a source of guidance.

Further details regarding the gamification exercises are presented here as the main interactive components of the scenario were incorporated in the gamification components. The four gamified exercises were identical for both versions of the scenario. As explained above, three of them focused on active patrolling and the fourth one on the decision-making process regarding active sheltering. The concept of active patrolling was central to the narrative and the experience intentionally moved participants back and forth from the outdoor to indoor environment, stressing the need to actively patrol both areas, and to prepare both the home and property. The first activity required participants to identify 10 items that needed to be removed to make their property safer as a fire approached (e.g. door mats, fuel cans etc.). The next activity was to find 5 items that would help in fighting a fire (e.g. hoses, pumps. gutter bungs). The scenario also took people inside and asked them to identify 9 changes that would assist in creating a safer space in the event of a burn over (e.g. moving flammable furniture, preparing water bottles, having access to woollen blankets wetting and rolling towels). During each of these three exercises, a timer was displayed to provide a sense of urgency and promote the feeling of stress, as was a counter to allow participants to know how many items they still had to find. In all cases immediate feedback was provided after identifying each item to increase the learning opportunity. Fig. 3 depicts VR scenes related to the three gamification activities of active patrolling both outside and inside the property.

The fourth exercise involved locating an appropriate place to shelter. To add pressure to the decision, fire alarms were blaring during the exercise, the noise of the fire and the pace of the narration was increased and deliberately changed to a more assertive tone as the situation becomes more perilous. Participants were told that the fire was going to impact their home and they needed to select a room that was a safer place to shelter. A plan of the home appeared on the screen and an arrow indicated the direction of the fire with six highlighted locations on the map; three being appropriate choices and three inappropriate, again, to emphasise that fire is a very context specific and you need to evaluate multiple options. Fig. 4 shows the house plan and the locations within the house which were presented to the participants at the first scene of the sheltering exercise.

The scenario allowed users to explore multiple locations until one of the appropriate one has been selected. Each selection was accompanied by voice-over feedback explaining whether the choice was appropriate or not and why. The purpose of this exercise was twofold: first, to provide reinforcement of the message that a fire is context specific but there are key pieces of information that can assist in making wise decisions; second, to provide a benchmark for knowledge when testing the effectiveness of the VR experience at the 3-month period.

2.3. Development and testing

After the parameters, narrative and gamification concepts of the scenario was agreed upon, images and videos of indoor and outdoor areas, were collected in order to build realistic virtual environments. Unity 3D game engine was employed to build the VR application including the embers, smoke and the fire visual effects. In the experiments Oculus Rift Consumer Version 1 VR head mounted displays were employed to immerse participants in the virtual environments. A professional journalist was used to conduct voice-overs. The duration of the VR experience averaged 20 min for most participants (exact times were automatically recorded for each participant). The scenario was tested with public participants and also with a group of information officers from the CFS. Key changes that occurred as a result of the testing was the addition of increased noise, particularly the blaring fire alarm as the smoke begins to enter the home. Other changes included: keeping doors in the home open until a burn over was imminent to promote the concept of active patrolling and erecting a ladder in the hallway to

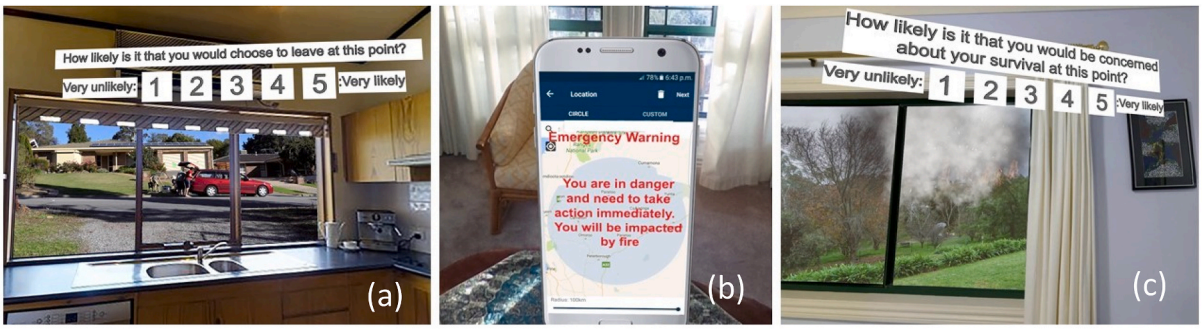

Fig. 2. Examples of socio-environmental cues presented as triggers within the VR environment (a) neighbours leaving, (b) emergency warning message; (c) visible smoke.

Fig. 3. Examples of VR scenes related to the three gamification activities (a) items that needed to be removed to make the property safer (b) items that would help in fighting a fire (c) items that would assist in creating a safer space in the event of a burn over.

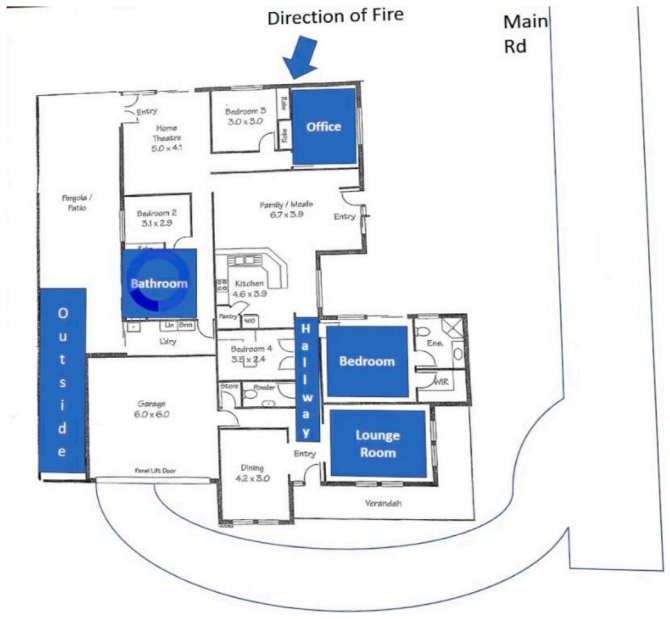

Fig. 4. A house plan of the sheltering exercise with the direction of the fire and six highlighted locations.

remind people to check the roof space for embers.

2.4. Survey development

The study applied several means of data collection: pen and paper questionnaire(s), a VR embedded survey and data collection through different VR activities, and an electronic survey. The first survey was a pen and paper survey conducted immediately before the experience. This survey comprised a series of questions related to bushfire experience, perceived knowledge of warning messages and socio-demographic factors. Participants were screened with the simple question "If the forecasted fire danger for tomorrow is "severe", would your plan be to: 1. Leave the property early (immediately or early in the morning); 2. Stay and defend the property; or 3. Wait and see what happens?" Those selecting option 1 were asked to complete the survey and were then thanked for their time, whilst those selecting option 2 or 3 completed the survey and were then set up with the relevant version of the VR scenario. Regarding VR embedded trigger questions, the 'wait and see' cohort were asked "how likely is it that you would choose to leave at this point?", while the 'stay and defend' cohort were asked "how likely is it that you feel concerned about your survival at this point?". For the last three triggers ('flames and ember', 'communication channels down', and 'power out' scenes), the question for both groups was the same: "How likely is it that you feel concerned about your survival at this point?". Table 2 shows the list of the VR embedded trigger questions for both 'wait and see' and 'stay and defend' cohorts. VR embedded trigger questions were measured using a 5-point rating scale, where 1 = not likely at all and 5 = very likely.

Data collection using a VR headset was based on gaze-based interaction. Users' responses to each question were recorded by tracking users' gaze on the item and allowing a blue circle to fill in as a confirmation of their choice. The other data collected from the VR experience were the data pertaining to the four gamification activities described in section 2.2.1. Although not presented as part of this paper, a questionnaire administered immediately after the VR experience recorded 32% of people were willing to participate in a final component of the study. The final survey was administered three months later via a SurveyMonkey link emailed to participants who had indicated their willingness to participate in the follow-up survey. This survey included 26

Table 2
VR embedded trigger questions for both 'wait and see' and 'stay and defend' cohorts.

Trigger	VR embedded questions	
	Wait and see cohort	Stay and defend cohort
Advice message	How likely is it that you would choose to leave at this point?	How likely is it that you feel concerned about your survival at this point?
Busy roads	How likely is it that you would choose to leave at this point?	How likely is it that you feel concerned about your survival at this point?
Watch and act message	How likely is it that you would choose to leave at this point?	How likely is it that you feel concerned about your survival at this point?
Neighbours leaving	How likely is it that you would choose to leave at this point?	How likely is it that you feel concerned about your survival at this point?
Visible smoke	How likely is it that you would choose to leave at this point?	How likely is it that you feel concerned about your survival at this point?
Emergency warning	How likely is it that you would choose to leave at this point?	How likely is it that you feel concerned about your survival at this point?
Flames and ember	How likely is it that you feel concerned about your survival at this point?	How likely is it that you feel concerned about your survival at this point?
Communication channels down	How likely is it that you feel concerned about your survival at this point?	How likely is it that you feel concerned about your survival at this point?
Power out	How likely is it that you feel concerned about your survival at this point?	How likely is it that you feel concerned about your survival at this point?

questions, focusing primarily on changes in behaviour or plans (e.g. whether participants created a bushfire survival plan), and remembered key pieces of advice from the VR experience. It also investigated their perception of the effectiveness of the VR scenario in comparison to the other means of information provision which were measured using a 5-point Likert scale, where 1 = strongly disagree and 5 = strongly agree.

2.5. Sample selection

Human ethics approval was gained to allow participation of individuals from age 16. This was chosen because it is common for parents to leave children at home alone from this age, and as such it was considered important to educate this age group. Information on the project was provided to all participants and consent was provided. Researchers checked with all participants before commencing the VR experience that they understood what it involved, to avoid any potential catalyst for post-traumatic stress if people had experienced a bushfire previously. The sample was a convenience sample where participants were invited to attend the VR events via multiple channels including news articles following a press release from the researchers, posters, Facebook posts and emails. All surveying was conducted at the beginning of the fire season and the 3-month follow-up survey was conducted towards the end of the fire season. Researchers were able to accommodate four VR participants concurrently on each of the data collection days. The scenario was tested at six locations across Greater Adelaide, the Mount Lofty region and the Riverlands in South Australia. The locations were: Hahndorf, Belair, Mawson Lakes, Gawler, Tea Tree Gully and Barmera. Hahndorf, Belair, Gawler and Tea Tree Gully are located in the peri-urban interface of Adelaide. The sampling at Hahndorf was conducted at a CFS event, as was the sampling in the rural location of Barmera. Mawson Lakes was used a central hub, which allowed for flexibility of people who couldn't make the assigned dates and times and the other locations. While most surveying occurred in areas prone to bushfires, a question on postcode was included to allow researchers to group data based on whether people resided in a high fire danger zone.

2.6. Data analysis

The data were entered into SPSS and then screened and assessed for normality before analysis commenced. The ordinal nature of the responses and non-normal distribution of the data, meant non-parametric tests were appropriate. All analyses were performed using SPSS version 25 software (IBM SPSS, Armont NY, USA). Descriptive statistics were used to describe and analyse the data pertaining to the characteristics of the responses, participant engagement, rating questions, gamification activities, as well as responses to socio-environmental cues within the virtual scenario. Mann–Whitney U tests were conducted to analyse data pertaining to participants' age groups, their perceived knowledge of bushfire warnings and assessing participants' sense of physical and emotional preparedness. Content analysis was conducted on open ended questions in the follow up survey using a code-as-you-go approach. Specifically, for the sheltering exercise, we evaluated if they understood they should be looking for a location with multiple exits and being far from the fire front. When evaluating their comments on the primary value of VR, content was grouped into three broad categories: informative, persuasive or heightened self-awareness.

3. Results

A total of 400 respondents participated in the study. This comprised of 17.25% who chose to leave early; 27.5% who indicated they would stay and defend and 55.25% who said they would 'wait and see'. An overview of these participants is provided in Table 3 and suggests the experience attracted a diversity of participants. Gender was quite evenly split amongst the 'wait and see' cohort but there was a greater number of male, compared to female participants in the 'stay and defend' cohort.

While attracting a broad range of participants, it was notable that "Facing Fire" did attract younger people (under age 35 years) which was an important target audience. Most of this younger group planned to leave early or 'wait and see' with only 23% stating that they have written bushfire survival plans. Moreover, only 19% of the 25–34 year-old age group in the 'wait and see' cohort stated that they have bushfire survival plans.

Table 3 also shows that the majority of people had witnessed smoke from a bushfire previously. Half reported there had been a bushfire in the area they resided in within the past 10 years and a small percentage had experienced property damage as a result of a bushfire. Two-thirds believed they lived in a bushfire prone area and almost one third had attended a CFS information session in the past 12 months. Many of those who planned to 'stay and defend' were members of the CFS. While the

Table 3
Overview of participants (n = 400).

	Wait and See	Stay and Defend	Leave early
Male/Female (%)	45/53	64/30	43/57
Over 35 years old (%)	67	83	26
Have got a written/agreed bushfire survival plan (%)	26	52	20
Members of the Country Fire Service (%)*	12	44	0
Had house or property damaged or destroyed by a bushfire (%)	5	14	5
Have had direct experience of a bushfire (%)	4	14	8
Know there had been a bushfire in the area they reside within the last 10 years (%)	46	65	56
Witnessed smoke from a bushfire (even from a distance) (%)	85	87	69
Witnessed a bushfire at some point during their life (%)	64	88	No data
Believe they live in a bushfire prone area (%)	64.1	83	48
Attended a CFS information session in the past 12 months (%)	23	44	5

*The CFS is operated by the state government but is largely dependent on over 13,500 volunteer members.

number of those who planned to 'stay and defend' and had a written bushfire survival plan was double those who planned to 'wait and see', the percentage was still alarmingly low (52%).

Further analysis of the age groups within the 'stay and defend' and 'wait and see' cohorts (Table 4) found there was a significant difference in the age range of participants who decided to 'stay and defend' (Mdn: 55–64 years old, Rng = 16- over75) compared to 'wait and see' cohort (Mdn: 35–44 years old, Rng = 16- over75)), with older people being more inclined to 'stay and defend' ($U = 8137$, $p < 0.001$).

Participants generally considered themselves quite knowledgeable about basic components associated with fire information. A total of 55% of participants expressed that they were confident in knowing the meaning of different CFS alerts and warnings. However, the perceived level of understanding for the 'stay and defend' cohort was significantly higher (*Mdn = 4*) in comparison with the 'wait and see' cohort (Mdn = 3), *U = 6736, p < 0.001*. A total of 77% of the 'stay and defend' group agreed or strongly agreed with the statement "I am sure that I understand the meaning of the different CFS warnings and alerts, compared to only 44% of the 'wait and see' group.

Similarly, while the aggregate data suggests the vast majority of participants believed they knew the meanings of each fire danger rating term (45% strongly agreed and 36% agreed), with only 7.3% disagreeing or strongly disagreeing with the statement "I am sure I know the meaning of the fire danger rating terms (catastrophic, extreme, severe, very high, high, moderate and low)", there was a significant difference between the two cohorts, with scores being significantly higher for the 'stay and defend' cohort (*Mdn = 5)* compared to the 'wait and see' cohort (*Mdn = 4*),*U = 8479, p < 0.001*.

Participants who believed that they lived in a bushfire prone area had significantly higher perceived knowledge of the meaning of different CFS alerts/warnings (*Mdn = 4)* than participants who did not believe they lived in a bushfire prone area (*Mdn = 3)*, *U = 8058, p < 0.001*. They also perceived they had slightly better knowledge of the meaning of fire danger rating terms (*Mdn = 4)* compared to people who believe they did not live in a bushfire prone area (Mdn = 4, *U = 9563, p = 0.003)*.

3.1. Effectiveness of the Facing Fire scenario

3.1.1. Engaging and educating a wide diversity of people

As demonstrated in Table 2, the "Facing Fire" VR experience engaged a wide diversity of people. This was also evident by the fact that through simple recruitment techniques we were able to keep all four of our VR stations continuously occupied on each sampling day.

Four gamification activities were used to assess and improve participants' understanding of fire preparation. Fig. 5 presents results for the first three of these activities and shows that people did best at finding objects they knew should not be there (e.g. flammable items), compared to finding items that would assist in the fighting or preparing for an imminent fire (e.g. equipment). While the 'wait and see' cohort appeared to do marginally better than the 'stay and defend' cohort in finding the items and also in terms of the speed of finding the items, there is no statistically significant difference between the two groups.

The final activity involved participants finding the best place to shelter given the fire was about to burn over their home. The results of this decision-making exercise are presented in Table 5.

By far the most popular choice of room to shelter in was the bathroom, for both cohorts and for both genders. There was no statistical difference based on cohort or gender in relation to this choice. Both cohorts who selected a poor choice first, typically selected an optimal choice second. The percentage of people making poor decisions of where to shelter (over 68%) compared to the percentage of people making good decision (32%), was more than double. However, it was positive to report that people chose to shelter away from the fire front and recognised the value of their home as a shelter, with few people selecting the office (the room closest to the fire front) or suggesting they would go outside. Learning retention related to this exercise was followed up in the survey 3 months after the VR experience, where participants were asked "***In the event of a fire burning over your home, what are two factors you should take into consideration when selecting the best place to shelter in the house?***" A total of 76% correctly identified either or both of the two tips provided in VR experience: the need to select a location with multiple exits and a location furthest from the fire front. A total of 41% identified both factors, 44% only recognised the importance of choosing a location further from the fire front, and 15% only remembered to choose a location with multiple exits.

Participants also perceived they learned from the exercise. Participants' responses of the VR embedded survey revealed that 74% of respondents strongly agreed and 23% agreed that they found the experience informative. In the survey three months after the VR experience 41% of respondents strongly agreed and 42% agreed that they learned new practical tips about fire preparation from the 'Facing Fire' scenario. Participants also perceived that the VR experience was very effective in helping them to remember bushfire tips. Table 6 shows that the vast majority agreed or strongly agreed that it was more effective than a range of alternative methods.

3.1.2. Promote understanding of the triggers that prompt protective actions

Studying the responses of the 'wait and see' cohort in facing the first six socio-environmental and warning cues as evacuation triggers revealed that receiving the CFS watch and act message acted as a first trigger for 37% of participants to leave. Another 20% first indicated they were most likely to leave when they saw their neighbour was leaving. Desire to evacuate the property did not decrease substantially even when they saw visible smoke in the area and received a verbal warning that evacuating was not a safe action anymore. A total of 14% of the 'wait and see' cohort never came to a point where they were indicated they were likely to leave. A close examination of this sub-group revealed that this group were mainly comprised of males (73%), who had witnessed a bushfire during their life (80%), and stated having knowledge of bushfire warning messages (63%). Despite an intention to "wait and see" on a severe fire danger day, they indicated they were prepared to

Table 4
Age and gender distribution among the "Wait and See" and "Stay and Defend" Cohorts (n = 328).

Age groups	Participants planning to "Wait and See"			Participants planning to "stay and defend"		
	N	Percent	Male and female numbers in age bracket (M:F)	N	Percent	Male and female numbers in age bracket (M:F)
Prefer not to answer	5	2.3%	1:2	1	0.9%	0:1
16–18 years	13	5.9%	5:5	0	0%	0
18–24 years	24	11.0%	12:12	10	9.2%	7:3
25–34 years	31	14.2%	22:9	8	7.3%	6:1
35–44 years	54	24.7%	22:31	13	11.9%	8:4
45–54 years	37	16.9%	15:22	21	19.3%	14:7
55–64 years	21	9.6%	8:13	23	21.1%	15:7
65–74 years	25	11.4%	7:18	28	25.7%	16:10
+75 years	9	4.1%	6:3	5	4.6%	4:1
Total	219	100%		109	100%	

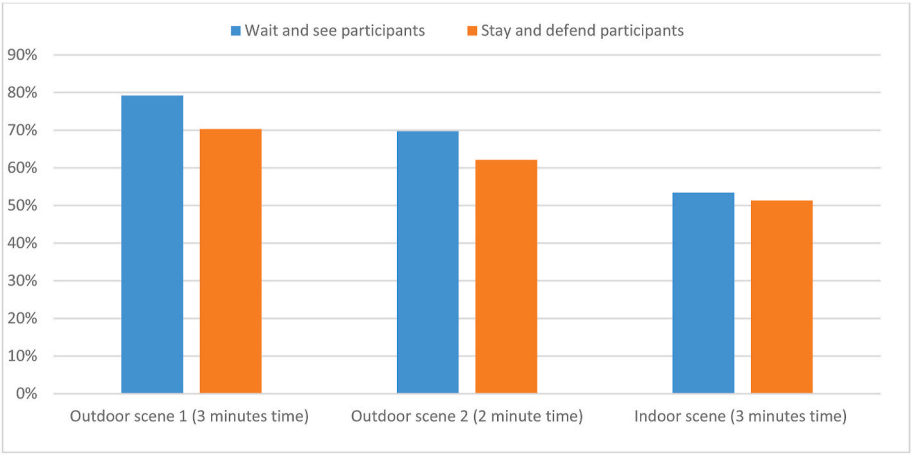

Fig. 5. Percentage of "Wait and See" (blue) and "Stay and Defend" (orange) respondents who found all items in each of the three observation activities. (n = 328).

Table 5
Initial selection of room to shelter in as a function of cohort (n = 328).

	Wait and See Cohort (n = 219)	Stay and Defend Cohort (n = 109)
Room Choices	% Selecting room first	% Selecting room first
Optimal Choices		
Bedroom	5.9%	4.5%
Lounge room	14.0%	9.9%
Hallway	11.8%	17.1%
Total	31.7%	31.5%
Poor Choices		
Bathroom	62.4%	64.0%
Outside	3.6%	4.5%
Office	2.3%	0%
Total	68.3%	68.5%

stay and defend (60%) and over one quarter stated that they had a written bushfire survival plan (27%).

We examined the results related to the nine cues in one graph for the level of concern for both cohorts. While it is expected that this concern rises throughout the scenario as the threats accumulate (Fig. 3), the gradient of the curve provides us with (Fig. 6) three important points:

(1) The base level of concern from the first CFS message is higher for the 'stay and defend' cohort compared to the 'wait and see' cohort and their overall response is more consistent and less erratic. Once they heard the 'CFS watch and act' message, the trajectory of concern for the 'stay and defend' cohort is very steady. The 'wait and see' cohort on the other hand, are not as concerned with the initial CFS advice message but then are increasingly concerned as the roads begin to get busier, they get the 'watch and act' message and they see neighbours leaving. The reported desire to leave decreases slightly when smoke becomes clearly visible and the narrator warns that it is not safe to leave when there is emergency warning in place and that they will be impacted by fire and must take shelter.
(2) For both cohorts, the trigger that manifests the greatest increase in concern (as demonstrated by the steepest curve) is the "CFS watch and act message", suggesting this is a key trigger.
(3) With the exception of the trigger "CFS emergency warning" there is a significant difference in response between the two cohorts at each stage of the scenario. It should also be noted that the 'wait and see' cohort heard a voice over telling them it was not safe to leave immediately after seeing smoke in the area. This likely influenced their reaction to triggers after this point.

Table 6
Perceived effectiveness of VR compared to other communication methods (n = 76).

	% strongly disagreed	% disagreed	% Neutral	% agreed	% strongly agreed
I think the scenario was better for me in terms of remembering tips about fire preparation than traditional written materials	0	2.6	9.2	30.3	57.9
I think the scenario was better for me in terms of remembering tips about fire preparation than reviewing information on the CFS website.	0	3.9	19.7	31.6	44.7
I think the scenario was better for me in terms of remembering tips about fire preparation than a 20-min public information session from the CFS.	0	3.9	32.9	32.9	30.3
I think if there was a link to an interactive virtual scenario on a website and I could watch it without requiring a headset, I would be very inclined to use this in my bushfire preparations.	1.3	5.3	9.2	46.1	38.2

Fig. 7 presents the mean results of the level of physical and emotional preparedness for male and female participants in both cohorts. It is based on two questions presented at the conclusion of the VR scenario: (1) I am physically prepared to defend my property; and (2) I am emotionally prepared to defend my property. There is no statistically significant difference in the physical ((U = 3005, p = 0.156) (W&S Mdn

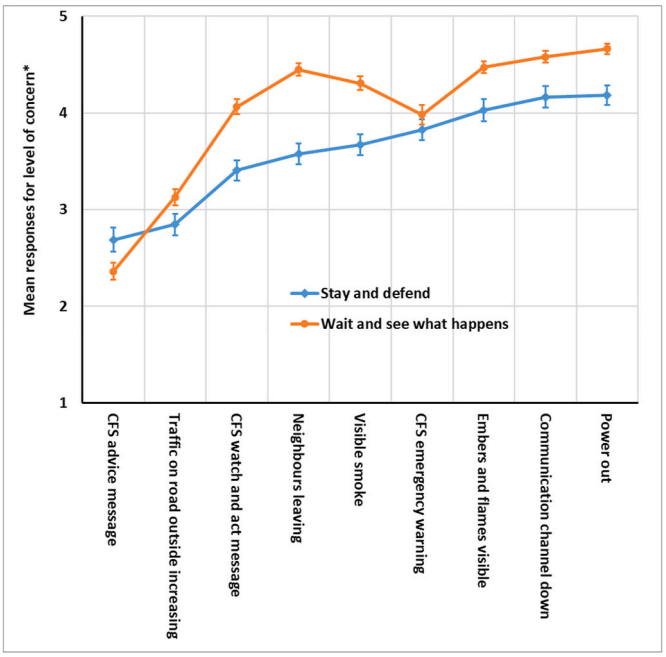

Fig. 6. Responses of "Stay and Defend" cohort (blue) and "Wait and See" cohort (orange) to socio-environmental cues and warnings as they progress through the VR scenario. *Scale 1 = not likely at all 5 = very likely.

= 3.4 and S&D Mdn = 3.7), or emotional preparedness (U = 3198, p = 0.438) (W&S Mdn = 3.5 and S&D Mdn = 3.7) between the 'wait and see' and 'stay and defend' cohorts for male participants. However, both physical (Mdn = 3.7) and emotional preparedness (Mdn-3.8) of female participants were significantly higher for the 'stay and defend' cohort compared to the female 'wait and see' cohort (Mdn = 2.6 and 2.5 respectively), U = 1375, p = 0.014 and U = 1302, p = 0.005 respectively.

3.1.3. Ability to promote behaviour change as measured by the development of a written bushfire survival plan

A key goal of the "Facing Fire" VR was to make the threat of bushfires more tangible for people so they would take the time to develop a written bushfire survival plan. To assess this, participants were contacted late in the fire season to complete a survey to see if they had made any changes three months after their VR experience. A total of 80 respondents completed the 3-month survey. When considering those who did not have a bushfire survival plan before the VR experience (n = 48) and excluding the people who did not live in bushfire prone area (n = 12), a total of 11 participants (30.5%) had completed a written bushfire survival plan within the 3-month period following the VR experience. The most common reasons given by those who had not completed a bushfire survival plan was they planned to leave early.

It was noteworthy that 81% of respondents reported in the three-month survey that they discussed bushfire planning with other family members, neighbours, colleagues or friends after experiencing the VR scenario. Examples of feedback included:

"I spoke to my neighbour and we compared plans."

"I discussed with friends who have newly moved to the hills."

"I discussed it with my family and we did a fire plan".

Almost three quarters of participants (74%) reported at the three-month period, that the "Facing Fire" VR scenario had influenced their behaviour and/or plans. Content analysis of open-ended responses revealed three main ways the VR experience had influenced their behaviour: first, they found the scenario informative, as illustrated by the following comments:

"It made me better informed about when would be a good time to leave, and what to do if trapped in a house unable to escape."

"I completely changed my previous BSP to make different strategies depending on the severity rating, which I had not thought of before."

Second, the scenario was considered persuasive.

"*I was more motivated to make my bushfire survival plan, and had more information to put in it*"

Numerous participants expressed they would now be more likely to leave early rather than wait to see what happens or to 'stay and defend'.

"I decided that I would leave rather than stay and fight the fire."

"It made me realise I'm getting too old to stay and defend. We are going to re-look at our plan and leave early if we can".

"It made me address our plan earlier than usual."

Third, participants found the scenario increased self-awareness in relation to how they may react in a fire situation. Many respondents were more aware of their emotional capacity after experiencing the scenario.

"*I realized I was not ready to deal with a fire"*

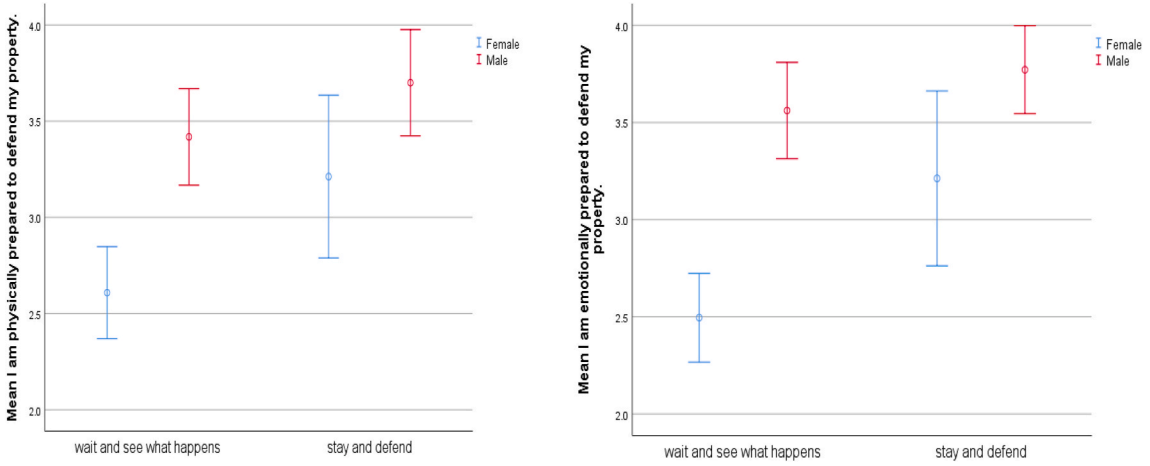

Fig. 7. Mean perceived physical and emotional preparedness of respondents following VR experience as a function of gender (females shown in blue, males shown in red, 95% CI indicated by vertical line).

"*Walking through the house with the visual technology opened my mind to my mistakes under pressure*"

"Being mindful of the range of sensory impacts (sounds -alarms, roar of fire), etc and how this would impact my actions (i.e. increase panic)".

Overall, the results of the study indicated that the VR scenario was effective in engaging and educating a wide diversity of people as evidenced by strong interest in the use of VR regardless of gender or fire experience, engaging younger people, and yet still appealing to middle age groups, as well as retaining good knowledge three months after the experience. The scenario was also realistic and increased participants understanding of the triggers which prompt protective actions and helped residents to recognise their actual physical and emotional preparedness level. Finally, experiencing the scenario influenced participants' plans or behaviour regarding bushfire preparation within three months after experiencing the VR scenario.

4. Discussion

People need to improve the way they prepare for bushfires. Despite major fires, greater information about increased fire risk due to climate change and pedagogically well-designed education programs using a variety of techniques, a large percentage of people are under-prepared, lack the necessary knowledge to survive a bushfire [35], consider 'wait and see' is a viable option, and/or are apathetic when it comes to preparation [56]. In this study 55% of people indicated if faced with a severe fire danger rating, they would 'wait and see' rather than act decisively. This figure is consistent with previous studies showing that the predominant response to bushfire threats is to 'wait and see' with some indicating over 45% and the others over 60% take the 'wait and see' approach before finalising a more decisive action [56]. This suggests fundamentally different approaches are needed. These results suggest great potential for the application of VR in improving bushfire preparation.

By setting up mobile VR stations at 6 different locations across multiple days, it was found that a diversity of people voluntarily participated in learning more about bushfire preparation. This diversity was measured in terms of age, gender, and experience with bushfire. Encouragingly, it did attract a substantial percentage of younger people who typically prepare less for bushfires and are characterised by a lower level of motivation and higher levels of perceived difficulty associated with bushfire preparation [57]. While the novelty of VR might explain some of this engagement, the value of novelty should not be dismissed as it is a powerful means of attracting markets [58,59]. While some may argue that as VR becomes more mainstream, the novelty factor will decrease, it should be recognised that this technology affords great potential for increasing novelty, for example through different scenarios involving different conditions, fire intensities, locations, and circumstances.

In terms of ages groups, the results did suggest that participants aged 25–54 years are most concerning in terms of their propensity to 'wait and see'. This is a busy time for people in terms of managing young families and building careers [57] but hopefully short, impactful exercises like "Facing Fire" might quickly educate them to make wiser choices. The scenario also seemed valuable to older people who had planned to 'stay and defend' but when placed in the scenario realised they might now want to reconsider this position.

The VR proved an effective education tool. For example, while the vast majority of participants from both cohorts (over 68%) made poor choices regarding a location to shelter, the feedback they received in the VR was obviously retained by many people as by the 3 month follow up, 41% could explain both criteria for the safe sheltering location and 76% could remember one. Lack of understanding of these criteria was demonstrated in the 2009 Victorian bushfires, where 27% of those killed, perished in the bathroom, a location that typically has only one exit and poor visibility [10,60,61]. Other important learning that occurred was many people realised as a result of the realistic rehearsal they experienced in the VR that they were not sufficiently prepared, either emotionally or physically.

The Australian Royal Commission into the Victorian Bushfires emphasized the need for greater research into the triggers that are important to different groups [61]. The VR provided valuable insights into the cues that are triggers for heightened concern. Not surprisingly, the 'wait and see' cohort' demonstrated behaviour that was most concerning. These results suggest the importance of socio-environmental cues as triggers on the decision to leave among the 'wait and see' cohort, which is consistent with previous studies [9,12,15,17]. Consistent with previous studies [12], the 'wait and see' cohort were most influenced by the behaviour of neighbours, a social cue which is inherently variable, and the emergency warning alert, which comes too late to optimize your chance of survival. Our results suggest that most of the 'wait and see' cohort's participants did not differentiate among the evacuation risks involved at different stages of the information flow during the imminent bushfire threat, meaning if they did not have a chance to leave during safer points (e.g. when they received CFS watch and act message), they still wanted to do so when it was no longer safe to leave (e.g. seeing smoke in the area or receiving emergency warning).

Observing 'no action' behaviour among 14% of the 'wait and see' participants, could be explained by the PADM process which suggests during an imminent threat at risk residents (i.e. those tempted to 'wait and see') may find themselves in a cycle of continuously searching for information and processing the information that causes them to lose valuable time for preparation or protective action decision making [14]. As noted previously, this group was dominated by males, people with high perceived knowledge of warning messages and previous exposure or experience of bushfire. It is suggested while they characterized themselves as likely to 'wait and see', they might have a greater tendency to stay rather than leave [56] and as such need to be more aware of the need for decisive action and active defending.

It was also revealed that women within the 'wait and see' cohort were more likely to feel both emotionally and physically unprepared, suggesting a need for gender-based training that can better equip and empower women. The CFS "Fiery Women" program [62] is an excellent example of such an initiative. One of the great advantages of VR is the ability to adapt and customize scenarios, so for example, a scenario targeting women possibly with responsibilities for older parents and children could be developed to help women identify issues and prioritise strategies.

The 'wait and see' cohort were also more likely to be younger and less experienced in fires suggesting marketing attention needs to be directed towards this group, focusing in particular on the necessity of multiple contingency plans when leaving is not an option. Unfortunately, after the VR experience, many respondents explained they didn't create a Bushfire Survival Plan, because they planned to leave early, suggesting this component of the VR needed to be emphasized more directly. Greater attention to explaining why the fire danger index rating is important is also warranted. While this system is currently under review, the results do suggest the limited value of a gradated system if people only perceive the "catastrophic" rating as important.

The results suggest greater consistency within the 'stay and defend' group who were also more likely to have a Bushfire Survival Plan and have thought through various scenarios during the development of that plan. The results demonstrated that the 'stay and defend' cohort were significantly more concerned by the CFS advice message, and this is likely because they considered this advice in conjunction with the description of the weather and the fire danger index rating that was provided in the introduction of the VR scenario. Consistent with previous research [56], most of the 'wait and see' cohort could be considered at-risk residents. Attention directed at how to encourage these people to be more decisive, more rapidly, will enable risk communicators and educators to design more effective interventions.

Of note, the changes in concern presented in Fig. 3, may replicate the well-documented "survival arc" [63], where people initial don't react quickly as they are in a state of disbelief or denial, then they deliberate before taking decisive action. For the 'wait and see' cohort, concern peaks when the neighbours leave, but then there is a decrease in concern leading to less willingness to leave which may represent they have passed the denial phase, deliberated and recognised they need to act decisively to stay and defend. Although concern is heightened following the emergency warning, this data may suggest people are going through some sort of modified survival process, which is positive in terms of the potential for VR as it suggests it is able to replicate reality to some degree. Not surprisingly, the curve for the 'stay and defend' cohort is more consistent as we would expect those people have deliberated about such a scenario previously and are more prepared to act rapidly. The potential benefits of VR to train people to be quicker in their "denial" and "deliberation" phases so they can act more decisively and rapidly is noteworthy.

Finally, as suggested by previous research [46], the VR demonstrated great potential in changing behaviour. A total of 31% of people who didn't have a bushfire survival plan before the VR experience and who lived in a bushfire risk area, had developed one by the 3-month survey. While this does not suggest the VR is a panacea, it does suggest the tool has great potential, especially when it is considered the 'Facing Fire' scenario was created to test the value of VR with the basic resources of university researchers and not with professional script writers or videographers which would likely further improve the potential of the tool. Again, we are not claiming that VR can solve the important problem of bushfire preparedness, indeed the Royal Commission into the 2009 Victorian bushfires noted that education programs are "but one necessary measure to be used in conjunction with other necessary measures, such as effective warnings and situational awareness in agencies and communities, community refuges, and measures to assist the creation of defendable space" (Parliament of Victoria, 2010: 7.) [8], but rather we believe that significant gains can be achieved through the application of VR. That said, the fact that the most common explanation of why people did not develop a Bushfire Survival Plan was they planned to leave early, suggests that many respondents were still not understanding that in some circumstances leaving early will not be possible and all people living in a bushfire prone area need to have a plan in case evacuation is not safe or possible.

Six key outcomes emerged from this research: (1) the problem of bushfire preparation is very significant with 55% of participants suggesting that they would "wait and see" rather than act decisively on a forecast severe fire danger day; (2) the VR format appealed to a diverse audience, including younger age groups who are often the least prepared for bushfires (only 23% of participants in the age group of $<$35 year-old stated that they have written bushfire survival plans); (3) consistent with previous research, the VR was effective in terms of participant's ability to retain information [42] and elicit a behaviour change over an extended period [46]; (4) the results showed greater attention needs to be placed on educating people to understand mechanisms designed to help them (e.g. warnings and alerts) and to recognise key triggers that could help them to be safer in a bushfire event; (5) there is a need for training customised to the needs and concerns of women which can better equip and empower women in a bushfire situation; and (6) VR offers a safe, and potentially cost effective and scalable tool to improve bushfire preparation.

In terms of future improvements to fire preparation focused VR scenarios, attention needs to be directed to the gamification concept. While it appeared popular with participants, attention seemed to be directed towards the speed of discovery, rather than the feedback. This difference was more pronounced with the 'wait and see' cohort, who had less experience and perceived knowledge of fire, although the difference in the time respondents took to complete the three activities was not statistically different. The success rate on each sequential game decreased suggesting a possible decrease in engagement that may be due to heightened stress but also probably that a threshold of novelty exists and we can't keep using the same game concept and expect people to maintain engagement. It is recommended that future work on VR incorporate less discrete gamification components, and instead a more sophisticated gamification concept that it is integrated more closely with the overall narrative. Caution should also be taken to ensure the game does not unjustifiably empower participants beyond their true ability or reward individualism, power or greed, which may work well in the world of gaming, but is the antithesis to the desirable approach in a bushfire situation.

Both versions of the 'Facing Fire' scenario successfully met the objective of engaging, educating and changing behaviour. To be scalable a shorter duration would be ideal but this was foremost a study to investigate the potential of VR and to increase our understanding regarding people's behaviour in a fire. The relatively short duration of the scenario meant we were limited in the number of twists that could be included, which may have compromised people's ability to comprehend the dynamic nature of fire and the need for contingencies. It is recommended that fire management agencies work collaboratively to develop a range of VR scenarios (e.g a fire while on holidays, a fire while you are out and other family members are home). With an increasing number of people having access to headsets in their own home the scalability of this communication form could be large. People may be more tempted to engage in a more sophisticated and elaborate narrative in the comfort of their own homes than in the public settings where this study was conducted.

5. Conclusion

Fire is not a game. It is a dynamic and complex process. However, the gains in engaging and educating people about fire that can be achieved through the application of VR and gamification are significant. The potential of VR is far broader than entertainment. We have shown it can facilitate memory retention and behavior change and that it can engage a broad spectrum of society in terms of age and gender. It is also readily adaptable allowing for great flexibility in the delivery. Extensive evidence suggests current strategies for public communication are not sufficiently effective. Profound improvements in public communication about fire are needed. We have shown in our study that VR has a vital role play to play in future fire education strategies.

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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