The Persuasive Power of Virtual Reality: Effects of Simulated Human Distress on Attitudes towards Fire Safety

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Abstract. Although virtual reality (VR) is a powerful simulation tool that can allow users to experience the effects of their actions in vivid and memorable ways, explorations of VR as a persuasive technology are rare. In this paper, we focus on different ways of providing negative feedback for persuasive purposes through simulated experiences in VR. The persuasive goal we consider concerns awareness of personal fire safety issues and the experiment we describe focuses on attitudes towards smoke in evacuating buildings. We test two techniques: the first technique simulates the damaging effects of smoke on the user through a visualization that should not evoke strong emotions, while the second is aimed at partially reproducing the anxiety of an emergency situation. The results of the study show that the second technique is able to increase user's anxiety as well as producing better results in attitude change.

Keywords: virtual reality, personal fire safety, distress, suffering, negatively-framed experiences, negative feedback, aversive feedback, emotions

1 Introduction

Simulation can persuade people to change their attitudes or behaviors by enabling them to observe immediately the link between cause and effect [6]. Although virtual reality (VR) is a powerful simulation tool that can allow users to experience the effects of their actions in vivid and memorable ways, exploration of VR as a persuasive technology is surprisingly rare. On one side, the literature on persuasive technologies tends to focus mostly on non-VR approaches; on the other side, the VR community explores several aspects of VR systems but omits persuasion aspects. The lack of studies of VR as a persuasive channel has been remarked also by the traditional persuasion literature, e.g. Guadagno and Cialdini [9] conclude their review on online persuasion and compliance by explicitly encouraging researchers to explore immersive virtual environments.

VR naturally support the delivery of various forms of negative and positive feedback to the user based on which actions she chooses and how those actions have have been categorized as wrong or right by the designers of the virtual environment. In this paper, we focus on providing negative feedback for persuasive purposes through simulated experiences in VR. The persuasive goal we consider concerns fostering awareness of personal fire safety and the experiment we describe specifically focuses on attitudes towards smoke in evacuating buildings during a fire.

The paper is organized as follows. In Section 2, we discuss in more detail negative feedback in the context of persuasion and further motivate our research. Section 3 describes the persuasive goal and the target behavior we consider. In Section 4, we illustrate the two techniques we have implemented. Section 5 and 6 respectively present the experimental evaluation and the results we obtained. Section 7 concludes the paper and introduces future work.

2 Related Work and Motivations

Meijnders, Midden and McCalley [14] tried to use multimedia and augmented reality tools to illustrate the consequences of global climate change. Although they hypothesized vividness to be a key factor in creating emotional risk responses and fostering attitude change, the effects obtained were modest even when vivid and concrete images and texts were used in combination with ominous sounds and music. They concluded that a further step needs to be explored, i.e. providing people with simulated risk experiences, particularly focusing on the sense of presence. Immersive VR has proved to be an effective tool to maximize sense of presence, leading to realistic human behavior in response to virtual events [22]. For these two reasons, our research project focuses on using immersive VR to simulate risk experiences for persuasive purposes.

It is well-known that one of the ways in which attitudes are acquired is through operant conditioning, i.e. a process in which individual responses that lead to positive outcomes or which permit avoidance of negative outcomes are strengthened through positive and negative feedback. Employing operant conditioning to reinforce target behaviors when they occur is one of the strategies advocated in persuasive technologies [6]. However, Kirman et al. [12] have recently claimed that the field of persuasive technologies is failing to explore and exploit the established body of empirical research within behavioural science concerning the constructive use of aversive feedback: according to their view, most persuasive technologies prefer to focus on rewards, and it is rare to see the full range of operant conditioning (positive reinforcement, negative reinforcement and punishment) exploited. However, work specifically aimed at studying negative feedback is starting to appear in persuasive technologies literature. For example, a recent study by Midden and Haam [15] has focused on social feedback from a robotic agent in the domain of energy saving behaviors, showing negative feedback to be particularly effective in obtaining compliance with energy conservation principles. Immersive VR has been shown to be an effective tool to induce states of fear and anxiety with aversive stimuli [1] or more generally induce various positive and negative moods [2]. In the experiment reported in this paper, we specifically test two different ways of providing aversive feedback for negative reinforcement purposes in VR simulations of risk experiences.

To facilitate memorization of the feedback provided by a persuasive application, we have also to consider that affect and human memory are related [3]: people are more likely to store positive information when in a positive mood and negative information when in negative mood (mood congruence effects). From this perspective, a persuasive application which presents incongruent feedback might not be helping the user to assimilate the persuasive message. For example, creating negative affect when the user walks into smoke in our simulation might contribute to the memorization of the negative experience and the associated message (you should avoid walking into smoke during an evacuation). To explore this aspect, the two techniques we designed aim at producing different levels of negative affect: the first should minimally increase it with respect to the level the user was already in at the beginning of the experience, while the second aims at noticeably increasing it. In this way, we can test if increasing negative affect might improve persuasion in simulation of risk-related experiences.

The important role of emotion in determining risk perception in people has been well documented in field and experimental studies, with negative emotions heightening the perception of risk [23]. Perception of risk as feelings (instead of rational analysis) is so widespread in individuals and in the way they form their attitudes that the term "affect heuristic" has been coined to describe these instinctive and intuitive reactions of people to danger [24].

Our work can also be seen as related to the debate on negatively-framed vs. positively-framed messages in persuasion, which has a long history in social psychology. In particular, studies of negatively-framed messages that appeal to fear (and the resulting anxiety) have shown induction of mild fear to be an effective strategy, while induction of greater levels of fear can backfire and result in less rather than more persuasion, due to the trigger of defensive reactions. The effectiveness of inducing mild fear further increases, and defensive reactions become less likely, when mild fear is paired with the proposal of a way out in terms of specific behavior that allows to avoid the presented fearful consequences, e.g. [13]. Recent persuasion literature is also exploring subtle threat cues, such as color priming, that can be added to a negatively-framed message to increase its effectiveness. For example, Gerend and Sias [8] have tested leaflets to promote a vaccination with the same textual negatively-framed message written on a red or grey background, showing that the red background increases persuasion. Our system aims to induce mild anxiety, and the two techniques we test should respectively deliver a low and an higher increase in anxiety by using less menacing or more menacing threat cues. However, there is an important difference with the literature: the huge wealth of studies on negatively-framed messages and persuasion has focused on traditional media (leaflets, newspapers, radio, TV,…) where the user passively watches or listens to an external message, while we immerse users in a highly realistic virtual environment in which they have to actively live an experience. This shift from negatively-framed messages to negatively-framed virtual experiences is a subject that deserves to be explored in the field of persuasive technologies.

3 Target behavior

In 2008, in the US alone, 20025 civilians were hurt (3320 dead, 16705 injured) as the result of structure fires [10]. And, adjusting for population, the fire death rate (i.e., the number of fire fatalities per million population) of some former USSR countries such as Latvia, Estonia and Russia is about ten times higher than the fire death rate of the US [5]. Current approaches to foster awareness of personal fire safety are based on solutions such as posting written instructions on room doors (e.g., the floor plan and fire safety guidelines one typically finds in hotels) or, much more rarely, conducting evacuation drills of buildings. Unfortunately, current approaches do not seem to be particularly successful: as pointed out by [21], one of the major reasons for deaths and injuries which could be preventable in fires is that people lack preparedness due to misconceptions on the dynamics of fire emergencies. Using VR might be a more effective strategy to face this critical problem: it could be much more engaging than written instructions, and it would be able to simulate fire emergencies in a much more thorough and realistic way than current building evacuation drill.

Among the possible topics in personal fire safety, the experiment described in this paper focuses on avoidance of smoke. This is an important topic for persuasion because, while people will tend to agree that it is better not to breathe smoke in a fire, studies of human behavior in actual fires have shown that people greatly underestimate the serious implications of smoke cues and smoke inhalation. For example, in the initial moments of a fire, upon smelling smoke or even seeing some smoke, occupants of buildings do not react, and deny or ignore the situation, waiting up to 10 minutes before starting evacuating the structure [20]. This waiting period significantly decreases chance of survival. Then, when occupants start evacuating the burning building, smoke does not deter them from moving in fatal environments: they often move through smoke instead of away from it [21]. Human movement in smoke becomes slow and should be absolutely avoided for its potential lethal effect [20]. The importance of smoke as a serious cue to be attended and a menace to survival from which one has to stay out as much as possible needs thus to be reinforced in the general public.

Of the three possible reasons that prevent the desired target behavior highlighted by Fogg's FBM model [7], lack of ability is the one that applies most to the case of response to smoke. Indeed, lack of motivation towards proper behavior is unlikely (most people want to survive a fire), and the lack of a proper trigger can be excluded (clear olfactory and/or visual cues present themselves to trigger the behavior). The problem is to persuade the user about the right behavior to choose in response to the trigger, and a VR simulation could be an ideal tool to this purpose, presenting the user with the effects of her wrong or right choices in a vivid and memorable way.

4 Employed Persuasive Techniques

The virtual experience we have created allows the user to realistically experience an evacuation of a burning building and try for herself the effects of staying in smoke or avoiding it. Moreover, to provide aversive feedback when the user stays inside smoke, we test two different techniques which differ in emotional intensity and should provide different levels of increased anxiety.

The emotional intensity of the first technique (called LowEmo in the following) should be low and increase user’s anxiety very mildly or not at all. The technique shows the negative effects of smoke on the user through an energy bar (Figure 1), similar to those employed in some videogames. Negative feedback is provided by having the energy level in the bar progressively decreasing when the user is inside smoke.

(a)

(b)

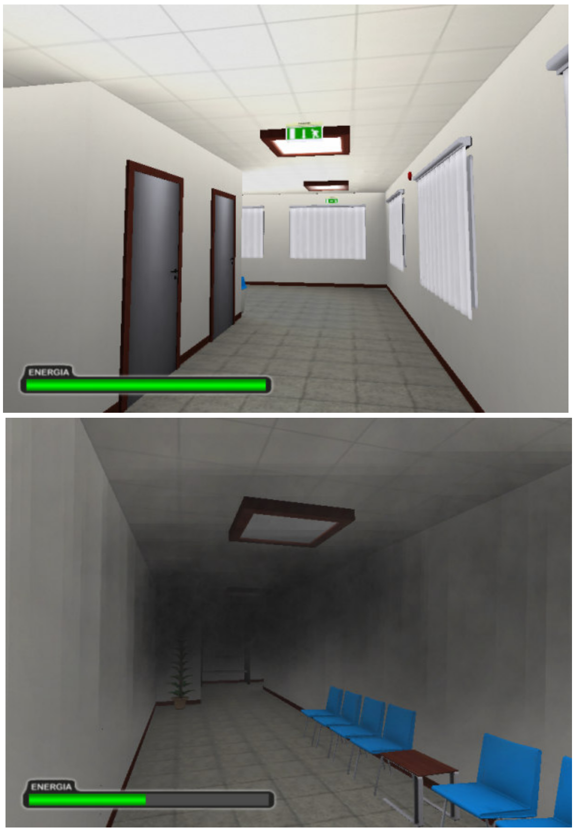


Fig. 1. Providing negative feedback to the user through an energy bar in the LowEmo technique: (a) the user is fully healthy, (b) the user is being damaged by smoke inhalation.

The emotional intensity of the second technique (called HighEmo in the following) should be high and increase user’s anxiety noticeably. This technique is based on the visual and audio feedback often employed in first-person shooter videogames (see, e.g., Call of Duty [4] and Mirror’s Edge [16]), augmented with an original idea we propose in this paper. The negative feedback inspired by videogames and provided when the user is inside smoke consists of: a digitized actor’s voice producing sounds of human suffering which become more and more disturbing as damage increases;

progressive reduction of the field of view (Figure 2a) to simulate tunnel vision phenomena which occur in extreme stress conditions; a sequence of red flashes (Figure 2b) synchronized with heartbeat sound; a white flash when the character is near death.

(a)

(b)

Fig. 2. Tunnel vision phenomena (a) and red flashes (b) in the HighEmo technique.

The original idea we added to these audio-visual stimuli in the HighEmo technique exploits biofeedback to induce anxiety, and is based on the fact that hearing our own heartbeat change and become abnormal is a cue that can induce anxiety and fear. For example, studies of panic patients have shown that they rate cardiac symptoms as the most fear provoking feature of a panic attack, and just hearing digitized files of abnormal heartbeat with a pair of headphones can be a fear-relevant cue for anxiety sensitive individuals [19]. We used a pulsioxymeter attached to the user's earlobe to detect her cardiac frequency and used this data as follows: (i) when the user is not in a dangerous situation in the virtual environment, we play her heartbeat sound in the headphones she wears so that she gets used to hearing her individual hearth feedback and its variations while she explores the world, (ii) when the user enters smoke, we digitally alter the speed of the replayed heartbeat to give her the impression that her own heartbeat is becoming abnormal (as it would happen in a real emergency), (iii) when the user exits smoke, we progressively revert to the replay of her actual heartbeat.

We hypothesize that both techniques should be effective in changing attitudes of users towards smoke in fire emergencies, but HighEmo should create more anxiety in users. Therefore, for the reasons discussed in Section 2, we also hypothesize that HighEmo should give better results than LowEmo in changing users' attitudes towards smoke and smoke avoidance in fires.

5 Methods

We recruited 26 subjects (19 male, 7 female) through personal contact: most of them were university students enrolled in different degree programs (engineering, medicine, computer science, business administration, architecture). Age ranged between 19 and 29, averaging at 23. They were all familiar with 3D videogames, 14 of them liked first person shooters to some extent, and 4 of them played first person shooters frequently. They were volunteers who received no compensation for participating in the experiment.

Subjects were split in two groups (LowEmo and HighEmo). All subject went through the same virtual experience of a fire emergency: the only difference was the way aversive feedback was provided during the experience (the LowEmo technique was employed for the LowEmo group, and the HighEmo technique for the HighEmo group). The virtual experience was implemented using C# and NeoAxis [17], a game engine based on the Ogre rendering engine [18]. The narrative was strictly linear: we arranged a preset sequence of events to occur regardless of subjects' movement speed or paths followed in the environment. As pointed out by [11], this way of organizing a virtual experience can be seen as an application of reduction and tunneling strategies [6]. During the experience, the subject was surrounded by smoke at preset instants in time, no matter where she went to in the environment: the first time she was surrounded by smoke she was going to suffer damage but not to die, while the second time she was going to die leading to the conclusion of the experience.

For subjects in the HighEmo condition, we used cardiac baseline data acquired at the beginning of the experiment to control how to alter heartbeat sound when the subject was in the smoke. More specifically, the frequency of altered heartbeat was set to double the baseline (e.g., the heart rate of a subject with a baseline of 75 BPM would progressively rise to 150 BPM when inside smoke).

Subjects were assigned to the two groups in such a way to obtain similar distributions in age, liking of first person shooter games, cardiac baseline and state of anxiety measured before the virtual experience.

To measure subjects' state anxiety before and after the virtual experience we used the State-Trait Anxiety Inventory Form Y (STAI) [25], which allows researchers to measure state anxiety through 20 questions that ask how much the subject agrees with sentences about her current state (e.g., "I feel safe", "I feel relaxed", "I feel nervous", "I feel worried",…) on a 4-point Likert scale (1=Not At All, 2=Somewhat, 3=Moderately So, 4=Very Much So). Based on the answers, STAI assigns a score ranging from 20 to 80 to indicate how high is the subject's state anxiety.

We measured attitudes towards smoke in fire emergencies before and after the virtual experience in terms of cognition, presenting subjects with two questions: a general one about the danger of smoke ("How dangerous is smoke during a fire?") and a more specific one about personal behavior ("During a fire, how important is that you avoid coming into contact with smoke?"), on a 5-points Likert scale (1=Not At All; 5=A Lot). Considering the facts previously summarized about smoke and human behavior in fires, the most appropriate answer is 5 for both questions.

5.1 Procedure

Subjects were welcomed in the lab and clearly informed that they could decide to refrain from continuing the experiment at any time without the need for providing a reason to the experimenters. This is particularly important in experiments that can induce anxiety due to the chance that subjects might find the experience too stressful and change their mind about participation.

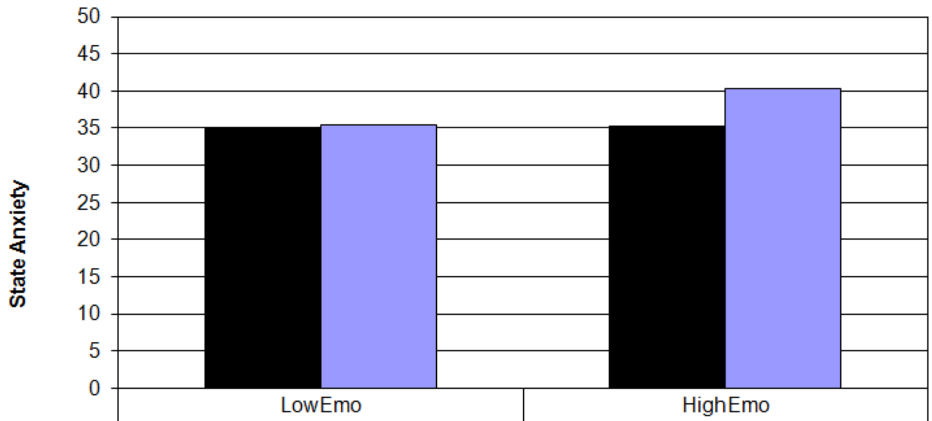
First, subjects filled the STAI and the cognition questionnaires to assess their state anxiety and attitudes before the experience. Then, we attached the pulsioxymeter to their earlobe and measured for 3 minutes their cardiac frequency to determine their baseline. Although this step was strictly needed only for those subjects who were going to experience the HighEmo condition, we carried it out to distribute subjects in a similar way in the two groups also respect to physiology, and to avoid introducing a possible confounding factor in the procedure.

Then, subjects donned a stereoscopic head-mounted display with 800*600 resolution, 31.2° field of view, and 3DOF head tracker. First, they were immersed in a training environment to familiarize with the controls for navigating the environment and for opening doors, based on a Nintendo Nunchuck joystick: the up and down commands on the joystick allowed subjects to move respectively forward and backward in the virtual environment, while the right and left commands were used to rotate respectively right or left in the environment. When subjects approached a closed door in the environment, the words "open door" clearly appeared in the environment and they could open it by pressing the trigger button on the joystick. The training environment was a building through which subjects could freely move and open doors. The experimenter indicated which training goal to achieve following a preset fixed sequence (move around with the joystick, look around by physically moving the head along the 3 tracked degrees of freedom, follow a path indicated by arrows in the training environment, try to open some doors, go look some objects very closely).

After completion of training, the virtual experience started. The subject was immersed in a room of a new, large building and was told to evacuate it because of a possible fire. After 1 minute, regardless of the location reached by the subject, she was surrounded by smoke coming from all directions. At this point, negative feedback was provided based on which group (LowEmo or HighEmo) the subject belonged to. No matter what actions subjects took, the smoke cloud kept surrounding them for 30 seconds. Then, smoke retreated and the parts of the environment in which the subject moved were smoke free for 1 minute. Finally, smoke surrounded again the subject for 30 seconds until she died (the size of the virtual building was set to ensure that it was impossible for anyone to exit the building within the time length of the experience). When the character died, the environment faded away, everything became black and a white message appeared informing the subject she did not made it. After 10 seconds, we invited the subject to remove the pulsioxymeter and the head-mounted display, and administered again the STAI and attitude questionnaires. Finally, subjects were briefly interviewed about their thoughts and feelings on the experience.

6 Results

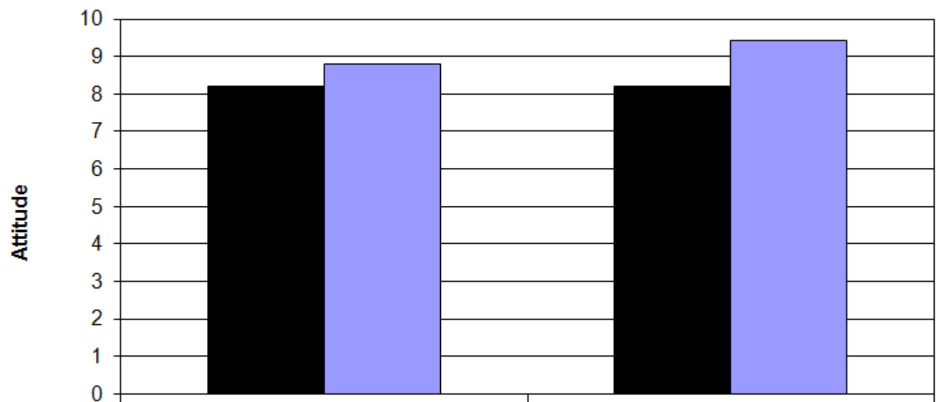
State anxiety measured before and after the experience in the two groups is shown in Figure 3. The analysis of anxiety increase within each group (Wilcoxon test) confirmed our hypothesis: increase in anxiety was negligible and not statistically significant with LowEmo ($p>0.05$), while HighEmo significantly increased subjects' anxiety ($p=0.01$). The difference in anxiety increase between the two groups is also statistically significant (Mann-Withney test, $p=0.046$).



	LowEmo	HighEmo
Before	35.15	35.31
After	35.46	40.38

Fig. 3. State anxiety in the two groups, before and after the experience.

Considering attitudes towards smoke in fire emergencies, a few subjects (3 in the LowEmo group and 4 in the HighEmo group) were already fully persuaded before the experience and scored the maximum of 5 on each of the two questions. Therefore, it was impossible for the experience to improve the score for those subjects: they scored the ideal total of 10 before as well as after the experience. The majority of subjects (10 in the LowEmo group, and 9 in the HighEmo group) had instead lower, non-ideal scores before the experiment (average: 8.20 for the LowEmo group, 8.22 for the HighEmo group), making them eligible targets for our attitude change attempt. Focusing on these subjects in the two groups, Figure 4 illustrates the obtained change in attitude: with the LowEmo technique, average score showed some increase (from 8.20 to 8.80) while with HighEmo the increase in score doubled (from 8.22 to 9.44, coming very close to the ideal 10). Moreover, while less than half (4 out of 10) subjects positively changed attitude after the experience with the LowEmo technique, almost every subject (8 out of 9) positively changed attitude after the experience with HighEmo. The analysis of change within each group (Wilcoxon test) showed that HighEmo significantly changed attitudes for the better (p=0.018), while the change obtained with LowEmo was close to significance (p=0.057). The difference in attitude change between the two groups is also statistically significant (Mann-Withney, p=0.032).



	LowEmo	HighEmo
■ Before	8.2	8.22
□ After	8.8	9.44

Fig. 4. Attitude change in subjects who were not already fully persuaded before the experience.

In qualitative free comments acquired with the final interview, many subjects expressed disappointment about their “death” in the virtual experience. Many said that they would have liked to replay the simulation to “win” the second time. In this sense, the negative experience might also be a motivator to acquire specific skills in a virtual training context.

Some subjects expressed surprise about the considerable damage that walking in smoke inflicted them or about the fact that they died without ever seeing fire. A few of them said that they had always believed people die in fires because they burn and they did not realize death can come before one sees or is touched by flames.

All subjects were impressed by the experience, at various levels. Almost everyone said that the experience felt “very real”. In the two most emotional recounts, being inside the virtual smoke was described as an experience that “frightened me” by one subject and that “made my head spin” by another subject.

It is interesting to note that none of the subjects noticed the tunneling they were subjected to: they simply believed to have played a sort of simulation game and lost.

7 Conclusions

To the best of our knowledge, our research is the first to study persuasive effects of immersive VR and game engine technologies in the fire safety domain. Moreover, we focused on the scarcely explored topic of aversive feedback in persuasive applications, and proposed a novel way to produce aversive feedback for simulated risk experiences that augments the audio-visual stimuli of first-person shooter videogames with a biofeedback technique. Overall, the experiment showed that immersive VR can be an effective tool for changing attitudes concerning personal safety topics. Moreover, emotional intensity of the employed feedback techniques turned out to play a role: the low emotion technique produced a small, not statistically significant attitude change, while the high emotion technique produced a larger and statistically significant change. The results we obtained seem to be consistent with the discussion of emotions and negative affect in persuasion literature sketched in Section 2 and highlight that negative affect can be used for beneficial persuasion purposes. This should be taken into account by designers of persuasive applications that deal with risk experiences, who could otherwise be tempted to omit or too heavily water down content related to human suffering and death.

Questions that arise from the current study and that will be the subject of future work concern the possibility of further increasing negative affect beyond the HighEmo technique and if this possible increase would result in more persuasion or could instead be detrimental, resulting in defensive reactions on the subjects' side.

Although this paper analyzed in depth some aspects of our current work, the project we are carrying out has a larger scope and is producing an application that deals with the different lessons one should learn about personal fire safety, combining several features of videogames and simulations (levels, challenges, points, tutorials, debriefings,…) to further increase user's engagement and persuasion.

From the evaluation point of view, we plan to extend our analysis to additional physiological measurements (skin conductance, respiratory rate, temperature) besides hearth rate, for analyzing subjects' stress levels at each instant of the virtual experience. Another important aspect for future work concerns the study of compliance with the lessons learned in the simulations: to this purpose, some of our simulations will be set in a 3D reconstruction of our university building, to facilitate the study of transfer effects to the real world.

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