Desktop Virtual Reality for Emergency Preparedness: User Evaluation of an Aircraft Ditching Experience under Different Fear Arousal Conditions

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Abstract

Virtual Reality (VR), in the form of 3D interactive simulations of emergency scenarios, is increasingly used for emergency preparedness training. This paper advances knowledge about different aspects of such virtual emergency experiences, showing that: (i) the designs we propose in the paper are effective in improving emergency preparedness of common citizens, considering aviation safety as a relevant case study, (ii) changing specific visual and auditory features is effective to create emotionally different versions of the same experience, increasing the level of fear aroused in users, and (iii) the protection motivation role of fear highlighted by psychological studies of traditional media applies to desktop VR too.

CR Categories: H.5.1 [Information Interfaces And Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities; H.5.2 [Information Interfaces And Presentation]: User Interfaces—Evaluation/methodology

Keywords: Virtual Reality, Emergency Preparedness, Training Systems, Fear arousal, User studies, Aviation Safety

1. Introduction

Since its early years, virtual reality (VR) has been used for training professionals in facing dangerous, life-threatening situations they could encounter in their real-world duties such as aircraft piloting or military operations. The use of (immersive or desktop) VR for preparing the general public to face emergencies has been instead scarcely studied. In this paper, we focus on the design and evaluation of virtual experiences for emergency preparedness of common citizens, aiming at advancing knowledge in three different directions. First, we propose a 3D interactive simulation of an emergency situation aimed at the general public, and study its possible effectiveness for emergency preparedness. Second, we propose and test an approach to arouse two different levels of fear when modeling an emergency situation in VR, evaluating if the intended scarier version of the experience is actually scarier than the other version. Third, we investigate links between virtual emergencies and psychological theories such as Protection Motivation Theory [Rogers 1983; Floyd et al. 2000; Milne et al. 2000] that provide models of how - under certain conditions - fear motivates people to protect themselves by accepting recommendations about their health and safety and changing their attitudes and behaviors accordingly.

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This is the accepted version of the paper. The DOI of the version of record in the ACM Digital Library is http://dx.doi.org/10.1145/2671015.2671025

The paper is organized as follows. In Section 2, we discuss VR for emergency preparedness of the general public, briefly introduce the psychological theories we propose to consider in the design and evaluation of VR for emergency preparedness, and provide motivations for our research. Section 3 illustrates the virtual experience we developed, while Section 4 describes the approach to make the experience scarier. Section 5 and 6 present the experimental evaluation of the two versions of the virtual experience and its results. Section 7 and 8 discuss the results and conclude the paper by outlining future work.

2. Related Work and Motivations

2.1 VR and Emergency Preparedness

VR, in the form of 3D interactive simulations of emergency scenarios, is increasingly applied to training first responders [Andreatta et al. 2010; Backlund et al. 2007; Cha et al. 2012; Cohen et al 2013; Knight et al. 2010; Xu et al. 2014] and other professionals [Ahman 2011, Buttussi et al. 2013; Manganas et al. 2004; Stone et al. 2009] in handling emergencies. Some systems were shown to be effective for professionals, e.g. emergency medical responders [Andreatta et al. 2010; Buttussi et al. 2013; Knight et al. 2010] or firefighters [Backlund et al. 2007]. It is thus interesting to explore if and how VR could be effectively used for emergency preparedness of common citizens as well.

Aviation safety is a paradigmatic case study that highlights limitations of current safety education methods common to other domains. In general, improving the level of passengers' cabin safety knowledge positively affects their behavior in emergencies [Chang and Liao 2009], increasing the probability of their survival [Thomas 2003]. Being prepared also contributes to reduce stress and fear which, especially when combined with lack of knowledge about suitable behaviors, can produce a “cognitive paralysis” phenomenon where people do not take any action at all, leading to fatalities in otherwise survivable conditions [Leach 2004; Leach 2005]. Unfortunately, citizens tend to show lack of interest towards traditional safety education materials: most passengers do not pay attention to the safety cards and safety briefings currently employed by airlines and the few passengers who pay attention show an unacceptable level of comprehension [Corbett et al. 2008]. Different authors [Cosper and McLean 2004; Chang and Yang 2011] agree that preflight safety information should be made more appealing and more comprehensible, and recommend to develop new methods for passenger education.

This paper proposes to use desktop VR as a novel method for the following reasons. First, training passengers through 3D interactive simulations would allow to make safety education materials more attractive and to present aircraft emergencies in a thorough and realistic way that includes all the visual and auditory details of real emergencies. Indeed, a VR simulation can immerse its user in 3D aircraft emergency scenarios, where the challenge is to survive the emergency and user's survival is strictly dependent on learning to avoid common passengers' errors and choose the right actions while staying as far away as possible from danger. Second, desktop VR could be a less costly solution with respective to immersive VR and allows passengers to try simulations at home. possibly increasing exposure time to emergency preparedness content and promote repetitive rehearsal of safety procedures, which improves knowledge acquisition. Third, experiencing detailed virtual reconstructions of aircraft emergencies could also contribute to reduce stress and fear in the real emergency situations. Finally, the virtual experience could take place in high-fidelity 3D reconstructions of actual airliners. This would allow not only to learn general knowledge that applies to any aircraft emergency but would also allow people to familiarize with the different escape routes, seat configurations, location of emergency doors and slides available in the aircraft type they are going to fly with.

While pilots routinely use highly realistic simulations of emergencies in their training, no full, realistic and detailed simulation of an entire aircraft emergency aimed at passengers (as the one described in this paper) has been tried before.

2.2 Studying Fear in VR

A design issue that specifically concerns emergency preparedness for common citizens is how to communicate risk and how to provide safety recommendations through the virtual experience. This can be seen as a modern version of a well-known problem in communication psychology: when a message delivered to the general public aims at effectively fostering awareness about safe behaviors, to what it should appeal? An extensive literature - see [Ruiter et al. 2001] for a review - advocates the arousal of fear in the message recipient, and specific theories on this motivating role of fear have been proposed, e.g., Protection Motivation Theory [Rogers, 1983]. Numerous studies - see [Floyd et al. 2000; Milne et al. 2000] for meta-analyses - support the effectiveness of fear arousal in health and safety communications, provided that two main conditions are met. In particular, fear leads to attitude and behavior change if: (i) the threatening stimuli used to scare are accompanied by recommendations that are perceived by the recipient as effective to avert the threat, and (ii) the recipient feels capable of carrying out such recommendations in the real world. Scaring people about a risk without meeting these two conditions is counterproductive: fear appeal models predict that the individual will try to reduce the negative emotion (e.g., through risk denial and defensive reactions) instead of learning how to cope with the risk.

A realistic VR reconstruction of an emergency situation (e.g., fires, hurricanes, mass emergencies, terror attacks, transportation accidents,...) is inevitably scary to some extent as it contains threatening visual and auditory stimuli and evokes or shows possible negative consequences such as injury and death. However, since the above mentioned literature on using fear in health and safety communications has studied only traditional media (printed materials, radio and video messages) and not VR, nothing can be reliably concluded about the validity of such models in interactive, virtual experiences unless experimental studies are carried out, as we begin to do in this paper.

Another aspect we explore in this paper is how different designs of the same virtual experience can have different fear-arousing capabilities. This is of general interest to various areas of VR. Indeed, the need for manipulating fear in experimental studies conducted with VR arises in domains such as psychiatry [Baas et al. 2004; Freire et al. 2010] and neuroscience [Tarr and Warren 2002; Tröger et al. 2012] for the study of a wide range of theoretical topics, e.g., attention, learning and memory, executive functions, emotions, personality and individual differences. Moreover, fear-arousing virtual experiences are important for applications such as phobia treatment based on VR exposure therapy (VRET) that aims at progressive extinction of phobic responses [Krijn et al. 2004; Meyerbroker and Emmelkamp 2010]. Similarly, Stress Inoculation Training (SIT) protocols based on VR expose people to virtual versions of fearful situations they are likely to encounter in their life, see [Ahmann 2011; Hourani et al. 2011] for military training examples. The aim of SIT is to help users learn to control emotional reactions when facing those fearful situations in their life. Both VRET and SIT applications would thus benefit from tested design methods that allow one to carry the user through a series of increasingly fear-arousing versions of a virtual experience. Explorations of which techniques are effective to induce fear in VR and their relative strength are thus needed, and this paper evaluates one possible approach to create two versions, one with higher fear-arousing capabilities than the other, of the same virtual experience.

2.3 Self-efficacy and Emergency Preparedness

Self-efficacy, the belief an individual has on his/her ability to execute a behavior, is a psychological construct that can be very important in the domain of emergency preparedness. According to Social Cognitive Theory [Bandura 1997; Bandura 2001], this belief significantly determines performance outcomes, and different people with similar skills may perform differently depending on variations in their self-efficacy.

Positive associations between safety training, self-efficacy and attitudes toward safety have been found in the literature, confirming the importance of the self-efficacy construct also in the field of preparedness, see [Grau et al. 2002; Katz-Navon et al. 2007] for a summary. Gaining experience in performing the given behavior is a major factor that contributes to increase self-efficacy [Bandura 1997]. VR simulations could thus be beneficial, because they allow users to actually succeed in applying knowledge to a virtual life experience, instead of passively listening to traditional preparedness messages.

Increasing self-efficacy is particularly important in the domain of aviation safety, because passengers have a pessimistic and fatalistic attitude towards aircraft accidents, mistakenly believing that there is little hope of survival. In fact, statistics show otherwise: the majority of commercial jet airplanes accidents is survivable if passengers follow the correct procedures [Cherry et al. 2013].

3. The Aircraft Ditching Experience

The desktop VR simulation we created allows users to experience a full, realistic and detailed aircraft water landing (*ditching,* in aviation terminology) and evacuation scenario and try for themselves the effects of the possible (right or wrong) actions that passengers can take in such serious emergency situation. The simulation includes realistic sounds (e.g., messages from the captain and flight attendants on the PA system, voices of other passengers, the various aircraft and accident noises,…) and visuals (e.g., relevant objects such as life vests and exit door details, the crowd of passengers and different behaviors of individual passengers, the full cabin environment,…). In particular, we have situated the experience inside an accurate 3D reconstruction of the cabin of an Airbus 320 [Airbus 2014], one of the most used aircraft types in service. The reproduced emergency is inspired by the accident occurred to US Airways flight 1549 [National Transportation Safety Board 2010]. A few minutes after take-off, the aircraft suddenly loses thrust in both engines due to a severe strike with a flock of large birds, and is forced to ditch because lack of thrust makes it impossible to reach nearby airports.

By trying the virtual experience, users could acquire knowledge that greatly affects their safety in emergency landings: (i) fastening seat belts as soon as the plane (Figure 1) shows signs of instability, (ii) maintaining a brace position during all the emergency landing until the plane comes to a stop, (iii) where to find life vests (under the seat), (iv) when to wear live vests (before leaving the seat), (v) when to inflate life vests (only outside the aircraft), (vi) leaving luggage on the plane during the evacuation, (vii) reaching for the nearest exit, (viii) when an emergency exit should not be used (because the environment outside the door is dangerous as in Figure 2), (ix) locating an alternative exit in the presence of exits that cannot be used, (x) going towards the bottom of the slide raft (Figure 3) before sitting on it (to avoid slowing down the passengers who are following behind).

When users choose a correct action, they see the positive consequences in terms of progress towards survival. When a wrong action is chosen or a necessary right action is omitted, they receive negative feedback and a recommendation about proper behavior. The way such feedback and recommendation is provided depends on the type of error or omission. If in the real-world the specific error cannot (or is very difficult to) be corrected once made (e.g., opening a door that is under water, inflating the life vest while seated,…), the simulation pauses, a fading effect is applied and a brief textual recommendation is superimposed on the scene (see Figure 4) for 7 seconds. Then, the user is brought back to the part of the simulation in which (s)he took the wrong decision and (s)he can restart from that checkpoint.

If in the real-world the specific wrong action can instead be quickly corrected (e.g., if users take luggage and realize that it slows down evacuation, they can abandon it in a place where it does not affect evacuation; if they try to stand up from their seat and realize they have no life vest, there is still the possibility of reaching for the life vest under the seat,…), then the virtual experience is not interrupted and nearby passengers or flight attendants verbally give the recommendation to the user. However, if users still do not comply with the recommendation, then after 10 seconds the simulation pauses in the same way as it does with irreversible errors. Table 1 lists the sequence of main events the user has to go through in the experience and wrong/correct actions available in each of them.

Since our system is meant for use in safety information campaigns, a primary requirement was to make it accessible to a wide audience, so we designed it to run on common PCs and be usable also by people with no specific experience with 3D applications such as video games. In particular, to make it easy to control the avatar, we designed a simple point-and-click user interface, operated by using only the mouse. To look around and change direction, users move the mouse while holding the left button. To move forward in the current direction, they just hold the right button. The actions contextually available at each moment in the simulation are displayed on screen through semitransparent white icons as in Figure 5. When users move the mouse over an icon, a brief textual description of the corresponding command appears (see the icon near the bottom of the screen in Figure 5) and they can click on the icon to take the corresponding action.

Figure 1. *The aircraft in flight.*

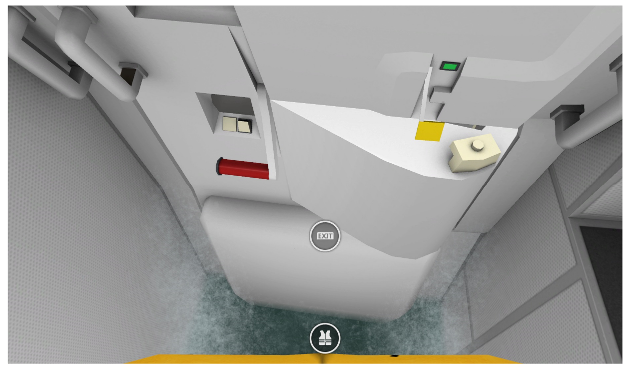

Figure 2. *Water flowing inside the aircraft from a rear door.*

Figure 3. *Seating on the emergency raft.*

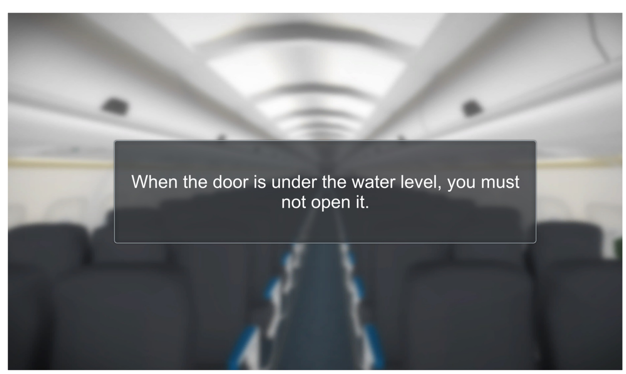

Figure 4. *A textual recommendation.*

	Event Sequence	Available WRONG Actions	Available RIGHT Actions
1	The aircraft is flying normally		Fasten seat belts
2	The aircraft impacts a flock of birds and starts shaking		Fasten seat belts
3	The captain orders passengers to fasten seat belts	Unfasten seat belts	Fasten seat belts
4	The captain announces emergency landing and orders passengers to assume the brace position	Unfasten seat belts, Sit normally	Brace
5	The aircraft lands on water	Unfasten seat belts, Sit normally	Brace
6	The crew orders to wear life vests	Stand up	Sit normally, Unfasten seat belts, Take and wear life vest
7	The user has worn the life vest, the crew is ordering evacuation	Inflate life vest	Stand up, Step towards the aisle
8	The user reaches the aisle (the closest exits are the rear ones)	Take luggage, Inflate life vest, Move towards front exits	Move towards rear exits
9	The user moves towards an exit (the closest exits are the rear ones)	Inflate life vest, Move towards front exits	Move towards rear exits
10	The user reaches the rear galley (exit door is under water level)	Inflate life vest, Open door	Move towards the front of the aircraft
11	The user moves towards the front of the aircraft (overwing exits are blocked)	Inflate life vest, Go back to rear exits or stay at overwing exits	Move towards front exits
12	The user goes through a front exit		Inflate life vest, Board raft
13	The user has inflated the life vest and boards the raft	Sit on raft	Move towards the bottom of raft
14	The user has reached the bottom of the raft	Go back towards exit	Sit on raft

Table 1. *Sequence of events the player has to go through and associated wrong and correct actions among the available ones.*

Figure 5. *User interface for action selection.*

4. Creating a More Intense Version of the Emergency Experience

To increase the emotional intensity of the experience with the aim of arousing a higher level of fear, we made changes to some graphical and audio details of the previously described experience. All other aspects of the experience (sequence of events and actions listed in Table 1, situations in which the simulation pauses to give a textual recommendation or the recommendation is provided by nearby characters, content of the recommendations given,…) were kept identical in the two versions of the experience.

The general approach we wanted to test to create two emotionally different versions of the same experience was to include the following graphical and audio details in the version that is meant to be scarier: (i) graphical depiction of the negative consequences of user’s errors on the avatar body, also including non-verbal sounds of suffering produced by the avatar when such consequences occur, (ii) graphical depiction of bodily damage also on the other virtual humans involved in the emergency, (iii) a state of distress in the facial expressions and in the emotional tone of the voices of the other virtual humans.

To apply this general approach to the aircraft ditching experience, we carried out the following steps. First, we considered user’s errors that lead to injury or death. The less intense version of the experience does not show the negative consequences of the error on the avatar body, while we graphically depicted the negative consequences in the more intense version of the experience. In the case of drowning, because the user opens a door that is under the level of water (or exits the plane without inflating the life vest), the avatar is flooded by (or falls into) water, all sounds become muffled and human suffocation sounds are played. Figure 6 shows some screenshots that illustrate how the negative consequence is depicted when a user opens a door that is under water level in the more intense version of the experience. In the case of head injury (because the user forgets to fasten seat belts or to maintain the brace position during the emergency landing), the camera shakes, the avatar hits the forward seat with the head, and blood spatters on the screen (Figure 7).

Second, we added injuries and blood stains to the skin of virtual humans involved in the emergency (the skin is instead normal in the less intense version of the experience). Third, we changed the neutral facial expressions that virtual humans have in the less intense version of the experience (Figure 8a) and make them distressed. The faces of passengers and, in particular, their mouths and eyes, were morphed to indicate worry or fear (Figure 8b). We changed the tone of passengers’ and flight attendants’ voices from neutral to tense, while keeping the wording of the sentences identical. Finally, we highlighted more intensely the negative consequence (engine damage) caused by the bird strike: while in the less intense version of the experience, the user learns of the engine damage by noticing a change in the engine sound and by hearing the voice of the captain on the PA system, in the more intense version we added smoke and flames coming out from the engines as visual cues of engine damage.

Figure 6. *Visualization of consequences of a user's error in the high intensity version of the experience: the avatar drowns.*

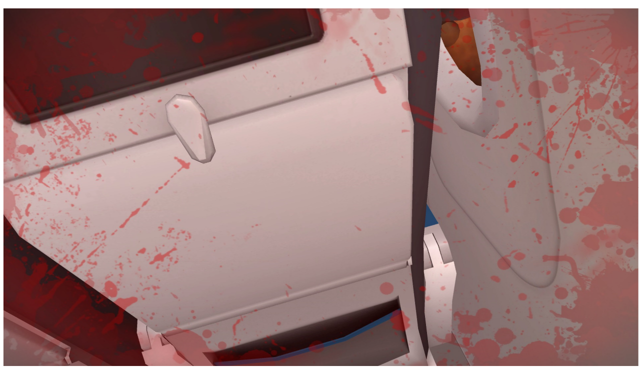

Figure 7. *The user is injured by impact.*

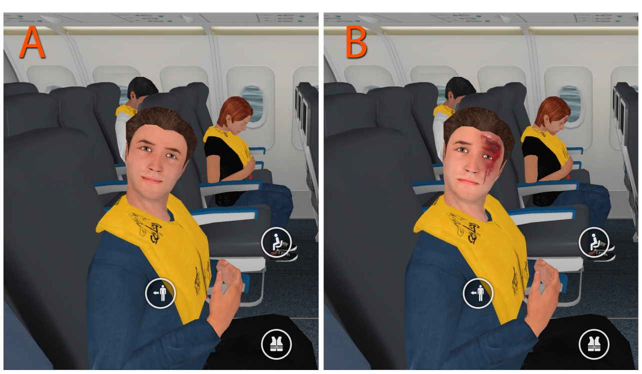

Figure 8. *The passenger seated near the user in the two versions of the virtual experience.*

5. User Study

We carried out a between-groups study to compare the fear-arousal capabilities of the two versions of the aircraft ditching experience and to assess if they can be useful for passengers' preparedness purposes. A group of participants tried the version (called "medium intensity" in the following) described in Section 3, while the other group tried the version (called "high intensity" in the following) obtained by making the changes described in Section 4.

Our hypotheses were: 1) the virtual emergency experiences improve participants' preparedness in terms of knowledge and self-efficacy, 2) the high intensity version has intrinsically higher fear-arousal capabilities than the medium intensity version, 3) the protection motivation role of fear that has been demonstrated with traditional media (see Section 2.2) holds also in desktop VR: participants who are more scared by trying the virtual experiences should gain more knowledge.

It is important to note that fear aroused by exposure to a given type of content depends both from how the content is designed and from the individual's sensitivity to that type of content. For example, an individual who is highly fearful of spiders and an individual who does not fear spiders at all will experience very different levels of fear when presented with the same images or videos of spiders. Therefore, the fear aroused by the virtual experiences in our case will not depend only on their design but also on how much the participant fears flight situations. It is thus fundamental to assess such individual difference and control for its role in fear arousal to pinpoint if the two designs actually have intrinsically different fear-arousal capabilities, as we predicted in the second hypothesis. To assess such individual difference, we used the 32-items Flight Anxiety Situations questionnaire (FAS), a validated instrument developed by [Van Gerwen 1999]. The FAS assesses anxiety related to different flight or flight-related situations (for brevity, and consistently with the literature, we will use the term "fear of flying" in the following). Each FAS item is rated on a 5-point scale, ranging from 1 (no anxiety) to 5 (overwhelming anxiety). The total FAS score is obtained by summing all item scores and can thus range from 32 to 160. The FAS is able to clearly discriminate among different levels of fear of flying. For example, [Nousi et al. 2008] contrasted a large group of people who sought support for fear of flying with a large group of people who did not: the mean FAS sum score was 102.42 (SD=22.48) for the first group, while it was 39.84 (SD=11.92) for the second group.

5.1 Participants

The evaluation involved a sample of 40 volunteers (22 M, 18 F), who received no compensation and were recruited through personal contact and a campus mailing list for general announcements. They were graduate and undergraduate students with various educational backgrounds (architecture, agricultural science, business administration, computer science, engineering, foreign languages, literature, and nursing) and people from other occupations. Age ranged from 19 to 33 (M = 23, SD = 2.94).

We assessed individual differences in video game use by asking participants to rate their frequency of game use on a 7-point scale (1=never, 2=less than once a month, 3=about once a month, 4=several times a month, 5=several times a week, 6=every day for less than an hour, 7=every day for more than one hour). Half of the users reported to play once or several times a month, 11 users more rarely or never, while 9 more frequently.

Frequency of air travel was assessed by asking participants for their number of flights in the last two years, as in [Corbett et al. 2008]. We made it clear that each flight had to be counted individually, so for example a round trip from airport A to airport C via a connection through airport B results in 4 flights. Answers ranged from 0 to 10 (M=2.18, SD=2.66).

Individual differences in fear of flying were measured with the previously described FAS instrument, and the FAS score ranged from 35 to 113 (M=61.58, SD=20.14).

The 40 participants were assigned to the two conditions in such a way that: (i) the proportion of men and women in each group was identical (11M, 9F): gender-balanced groups are particularly important in fear studies because gender can affect the outcome, see [McLean and Anderson 2009] for a review of how women tend to experience and report higher intensities of emotional experience than men, (ii) the two groups were very similar in terms of age, frequency of video game use, frequency of air travel, and fear of flying: lack of significant differences between the groups for the four demographic variables was confirmed by independent samples t-test.

5.2 Measures

5.2.1 Self-Reported Fear

To measure the level of fear experienced by participants, we followed [Ordonana et al. 2009], asking participants to rate 6 mood adjectives: scared, tense, anxious, uncomfortable, nervous, fearful. In particular, the adjectives referred to the sentence “This experience makes me feel…” and were rated on a 7-point scale (1=not at all, 7=very). The six ratings were averaged to form a reliable scale, Cronbach’s alpha=.91.

5.2.2 Physiological Arousal

To measure participants’ level of physiological arousal elicited by the two virtual experiences, we recorded electrodermal activity with a Thought Technology Procomp Infiniti system. In particular, we focused on skin conductance level (SCL), which is increasingly used in studies of fear and anxiety in VR, e.g. [Chittaro, 2014; Lister et al. 2010; Mühlberger et al. 2008; Tröger et al., 2012]. SCL is the more stable of the two components of the electrodermal signal and is typically used to measure the level of electrodermal activity during a given period of time [Andreassi 2007]. Before the virtual experience, we measured participants’ baseline values, i.e., the signal values that can be observed when participants are in a resting state. When analyzing physiological data, the participant’s baseline value has to be subtracted from the data recorded during the experimental condition, to separate the physiological responses to experimental stimuli from the intrinsic biological differences among participants [Andreassi 2007].

5.2.3 Knowledge

To measure participants’ safety-relevant knowledge about emergency water landing and evacuation, we used 10 questions: what to do in case of in-flight aircraft instability; what to do in preparation for impact; what to do before leaving the seat; which exit should be the first choice for evacuation; when it is not possible to use an exit; which exit should be considered if the first choice cannot be used; when the live vest has to be inflated; where the live vest is located; what to do after reaching a raft; what to do with one’s luggage. To avoid suggesting possible answers (e.g., as a multiple-choice questionnaire would do), participants were asked to answer verbally. Answers were audio recorded and later rated by the experimenter as correct or wrong following a codebook that indicated the possible correct answers. As a general criteria, for each of the 10 questions, only answers that were correct as well as complete were rated as correct, while all other answers (including partially correct and incomplete ones) were rated as wrong. Knowledge was measured as the number of correctly answered questions and thus ranges between 0 and 10. Participant’s knowledge measured before the virtual experience showed that participants were able to answer correctly only about half of the questions: means in the two groups were respectively 5.55 (SD=2.19) and 5.00 (SD=1.90). Lack of significant differences in initial knowledge between the two groups was confirmed by independent samples t-test.

5.2.4 Self-Efficacy

To measure self-efficacy, we designed a 6-item questionnaire, by (i) taking items from well-known self-efficacy questionnaires such as the General Self-Efficacy (GSE) scale [Schwarzer and Jerusalem 1995] and adapting them to our domain, e.g., “I am confident that I could deal with an emergency evacuation of an aircraft”, and (ii) following the recommendation on rigorous theory-based semantic structure for specific behaviors proposed by [Luszczynska and Schwarzer 2005], which leads to build items such as: “I would be able to deal with an emergency evacuation of an aircraft even if it has landed on water” or “I would be able to deal with an emergency evacuation of an aircraft even if some exits are blocked”. Each item was rated by participants on a 7-point scale (1=not at all, 7=very). Answers were averaged to form a reliable scale, Cronbach’s alpha=.90. Participant’s self-efficacy before the virtual experience was very similar in the two groups: means were respectively 3.13 (SD=1.30) and 3.28 (SD=1.22). Lack of significant differences in initial self-efficacy between the two groups was confirmed by independent samples t-test.

5.3 Procedure

Participants were told that the goal of the experiment was to evaluate, by collecting questionnaire as well as physiological data, an application that concerns what to do in an aircraft emergency landing. They were clearly informed that they could refrain from continuing the experiment at any time without providing a reason to the experimenter. This is particularly important in experiments that can arouse fear, because some participants might find the experience too stressful.

First, participants were seated, filled the initial questionnaire (age, frequency of game use, frequency of flight, FAS, self-efficacy) and answered the knowledge questions. Then, the experimenter explained the controls and the participant tried them on a very simple virtual environment that did not contain any fearful elements (an empty room with a lamp that could be switched on) to check that they had fully understood how to navigate and select actions. To do so, they were invited to look around, move forward, briefly explore, and finally reach the lamp and turn it on. All participants quickly understood the controls.

Then, we placed skin conductance electrodes on the intermediate phalanges of the middle and the ring fingers of the participant's non-dominant hand. Participants were asked to relax for two minutes to record their physiological baseline values. During baseline recording, a video with relaxing images and music was shown in a dim light. Participants could close their eyes and only listen to the music if they preferred. After baseline recording, they were asked to try the virtual experience. Since time pressure can affect arousal, we were careful not to impose any time limits and told participants that they could spend as much time as they wanted in the virtual experience. The application was run on a Windows PC (2.67 GHz Intel i7 processor, 6 GB RAM, NVidia GTX 480 graphic card) and displayed in full-screen mode on a 30" LCD monitor at WQXGA resolution (2560x1600).

6. Results

6.2.1 Self-Reported Fear

The self-reported fear measure was analyzed with a between-subjects ANCOVA, controlling for participant's fear of flying. The difference in self-reported fear was statistically significant, $F(1,37) = 6.23$, $p < .05$, $\eta_p^2=.10$, and fear aroused by the high intensity experience ($M=3.61$, $SD = 1.57$) was higher than the medium intensity experience ($M=2.96$, $SD = .89$).

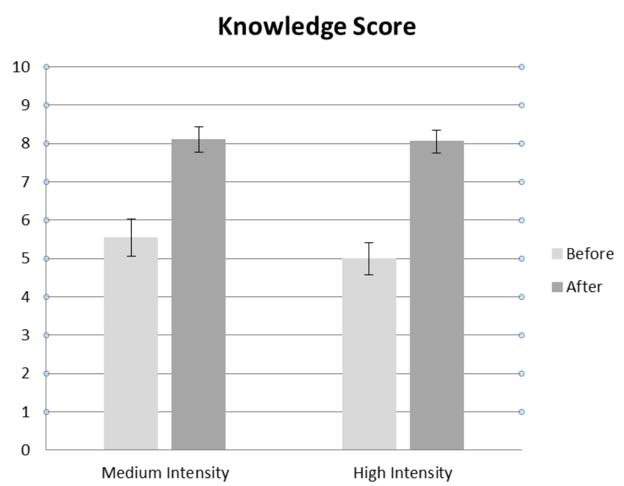

Figure 9. *Average knowledge score before and after trying the medium and the high intensity experiences.*

6.2.2 Physiological Arousal

After baseline subtraction, we identified SCL extreme outliers, i.e. values which are smaller than Q1–3*IQR or greater than Q3+3*IQR, where IQR is the interquartile range, Q1 the first quartile, and Q3 the third quartile. Extreme outliers were removed at the group level: only 1 extreme outlier was found (in the medium intensity condition). Then, we ran a between-subjects ANCOVA, controlling for participant's fear of flying. The difference in arousal was statistically significant, $F(1,36)=13.05$, $p=.01$, $\eta_p^2=.17$, and the average increase in SCL with respect to baseline values was .55 µS (SD=.31) in the medium intensity experience, and 1.77 µS (SD=.19) in the high intensity experience.

6.2.3 Knowledge

To test if trying the virtual experiences resulted in significant changes in user's knowledge, we run a mixed model ANOVA with time of measurement (before the experience, after the experience) as within-subjects factor and intensity of the experience (medium, high) as between-subjects factor. Results show a main effect of time of measurement, $F(1,38) = 64.8$, $p<.001$, $\eta_p^2=.63$, and no interaction between the within- and the between-subjects factor, indicating a statistically significant increase of knowledge with both versions of the experience. The average increase in knowledge score was 2.55 (SD=2.31) in the medium intensity group and 3.05 (SD=2.09) in the high intensity group (Figure 9).

We then assessed if protection motivation effects of fear that have been shown in people exposed to messages from traditional media occur also with the fear experienced with a different media (desktop VR), leading users to learn more recommendations. Since length of exposure to content can affect learning too, we took into account that users differed also in the amount of time they spent in the virtual experience. Therefore, we carried out a multiple linear regression on the 40 study participants, with fear and time spent in the experience as the independent variables. The dependent variable was the gain in knowledge, obtained as the difference between knowledge measured after and before the experience. Results indicate that fear as well as time spent in the virtual experience are significant predictors of gain in knowledge ($F(2,37)=7.360$, $p<0.01$) and account for 24.6% of its variance. Table 2 shows the individual regression parameters for the two variables.

Adj. R^2	Predict.	B	Stand. B	t	p
0.246	Reported Fear Time spent	0.519 0.011	0.310 0.379	2.184 2.670	0.035 0.011

Table 2. *Regression parameters for gain in knowledge.*

6.2.4 Self-efficacy

To test if trying the virtual experience resulted in significant changes in self-efficacy, we run a mixed model ANOVA with time of measurement (before the experience, after the experience) as within-subjects factor and intensity of the experience (medium, high) as between-subjects factor. Results show a main effect of time of measurement, $F(1,38) = 38.14$, $p<.001$, $\eta_p^2=.50$, and no interaction between the within- and the between-subjects factor, indicating a statistically significant increase of self-efficacy with both versions of the experience. The average increase in self-efficacy was 1.41 (SD=1.08) in the medium intensity group and .95 (SD=1.33) in the high intensity group.

7. Discussion

The results of the experiment confirm our hypotheses. First, they show that a desktop VR simulation can be effective for emergency preparedness of common citizens. Both versions of the experience significantly increased users' safety knowledge as well as self-efficacy, an important predictor of the likelihood that they will perform the learned actions when faced with the real-world emergency (as seen in Section 2.3).

Second, the approach we have followed to differentiate the visual and auditory presentation of the virtual experience was effective in obtaining the intended difference in fear aroused. Participants reported higher fear with the version of the virtual experience that was intended to be scarier. We controlled for participants' fear of flying in the statistical analysis and the difference in self-reported fear was significant. Physiological responses were consistent with this result, confirming and reinforcing it. Arousal measured through electrodermal activity was greater in the high intensity than in the medium intensity experience and, controlling for participants' fear of flying, the difference was significant. The high intensity version of the experience has thus intrinsically higher fear-arousal capabilities than the medium intensity version. These results are interesting also for the other purposes summarized in Section 2.2. For example, in a SIT protocol, each user could be exposed first to the less intense version and then move on to the more intense version when (s)he feels ready, to progressively habituate him/her to such stressful situation.

Third, the experiment was able to confirm that the protection motivation role of fear that has been demonstrated with traditional media (printed materials, radio and television messages) holds also in desktop VR. The more participants were scared by the virtual experience (which, as we have previously discussed, is due to a combination of user's sensitivity to flight situations and the design of the experience itself), the more new knowledge they acquired through it. As seen in Section 2.2, this motivating role of fear has been shown to hold only under certain conditions: the arousal of fear should be accompanied by the presentation of simple and effective actions to avert the threat. As we have previously illustrated, the inclusion of simple recommendations when the user made errors and the possibility to clearly see the effectiveness of the suggested actions by performing them in the virtual experience were central features of our design.

Since the amount of time participants spent in the virtual experience varied, we took it into due account, showing that also this factor contributed to knowledge gain. This relation was more predictable, because a lengthier exposure time to content increases the possibility of examining and memorizing it: the more time one spends in the virtual experience, the more opportunities (s)he has to pay attention to the knowledge presented and to possibly see specific situations more than once as a result of errors made. To better understand the reasons for different individual times, we checked if time spent in the virtual experience was related with participants' frequency of game use and the number of errors made in the experience. No significant correlation was found between frequency of game use and time spent in the experience. The second of the two correlations was instead significant ($\rho(40) = 0.43$, $p < 0.01$) and is rather obvious to explain: the more errors a user makes, the more frequently (s)he is brought back to the last checkpoint and has to repeat a part of the simulation.

To the best of our knowledge, the application we have presented is the first aimed at creating full experiences of aircraft emergencies from the passengers' viewpoint for aviation safety education purposes. The existing VR applications that modeled aircraft cabin environments pursue other purposes and fall into two main categories: (i) evacuation simulators, such as vrEXODUS [Galea 2001] or the Glasgow Evacuation Simulator [Johnson 2008], employed to predict the dynamics and outcomes of crowd egress (e.g., for evaluating aircraft designs), and (ii) VRET systems for the treatment of fear of flying, e.g. [Brinkman et al. 2010; Rothbaum et al. 2006]. Considering evacuation simulators, our application shares with them the focus on emergencies. However, those systems give priority to the predictive power of the simulation, and are not concerned with using high-quality graphics and sound to visualize the output of the simulation (e.g., the models representing virtual humans have very primitive shapes which in some cases reduce to cylinders) or with making the visualization emotionally engaging or usable by passengers. Considering VRET systems, our application shares with them the focus on providing passengers with a visual and auditory experience that is as similar as possible to the real-world one. However, while current VRET systems focus on normal flight events to treat patients who suffer from fear of flying, we focus on emergency situations to educate passengers about how to survive and also increase their self-efficacy. Moreover, looking at the VRET systems for fear of flying illustrated in the literature, our application exploits features offered by current game engines (e.g., efficient rendering of more detailed 3D models, combination of light maps and dynamic lighting, 3D audio from multiple spatial sources, real-time path planning of virtual humans,…) to obtain a more realistic experience.

8. Conclusions

This paper has explored three main research topics: (i) the effectiveness of desktop VR simulations for improving emergency preparedness of common citizens, using aviation safety as a relevant case study, (ii) the creation of emotionally different versions of a virtual emergency experience by changing specific visual and auditory features of the environment, (iii) the possible application to VR of fear appeal theories used in psychological studies of traditional media. The user study we presented advances knowledge about each of the three topics, showing that (i) the design we proposed in the paper for the desktop VR experiences is effective in improving emergency preparedness, (ii) specific visual and auditory features we included in the virtual experience are effective for increasing the level of fear aroused in users, and (iii) the protection motivation role attributed to fear in psychological studies of traditional media applies to VR too.

The ideas we have proposed could be easily adapted and applied to emergency preparedness domains different from aviation. Moreover, as seen in Section 2.2, the need for creating different levels of fear in VR arises also outside the area of emergency preparedness. Therefore, the proposed ideas can be of interest to any researcher and practitioner who needs to arouse different levels of fear with a VR experience.

The virtual ditching described in this paper was developed in the context of a project aimed at creating publicly available aviation safety education applications. For an example of a released application that illustrates in detail a brace position, see [HCI Lab 2014]. The virtual ditching experience will be part of a larger application that will feature multiple scenarios of emergencies, aiming at motivating users to try more than one virtual emergency, thus extending their exposure time to the safety content. Once the effectiveness of all scenarios will be tested on users, the application will be released on PC and Mac platforms.

To continue the investigation of the encouraging results we obtained on improving preparedness, we plan to conduct further studies with the aircraft ditching experience as well as with the future multiple-scenarios application. In particular, we will extend our attention to attitude and knowledge retention over time.

To continue the investigation of fear appeal theories in VR, we will consider other variables that have been studied in traditional fear appeals research. Finally, we want also to explore completely different approaches that try to make the virtual experience memorable without appealing to fear, e.g., evoking positive emotions by using humour.

Acknowledgements

This research is supported in part by a grant from the US Federal Aviation Administration (FAA). We are grateful to Mac McLean (FAA Civil Aerospace Medical Institute) for his precious feedback and encouragement.

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