This paper received the **BEST PAPER AWARD** at the 7th International conference on Persuasive Technology (PERSUASIVE 2012).

Citation Details:

Chittaro, L.: Passengers' Safety in Aircraft Evacuations: Employing Serious Games to Educate and Persuade. In: Bang, M., Ragnemalm, E. (eds.) PERSUASIVE 2012. LNCS, vol. 7284, pp. 215–226. Springer, Heidelberg (2012)

PERSUASIVE 2012 BEST PAPER

Passengers' Safety in Aircraft Evacuations: Employing Serious Games to Educate and Persuade

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Abstract. The field of persuasive technology has only recently started to investigate how virtual experiences of risk can be used to change people's attitudes and behaviors with respect to personal safety. In this paper, we aim at advancing the investigation in different directions. First, we extend the study to self-efficacy, which has been shown to be a predictor of future performance as well as an important factor for persuasion attempts which show negative consequences on people's health. Second, we increase the interactivity of the virtual experience, by designing and implementing a full serious game, in which the user can acquire knowledge about several aspects of her personal safety, and we investigate also effects of the virtual experience on user's knowledge. Third, we focus on an important problem to which serious games and persuasive technology have never been applied before, i.e. educating passengers about personal safety in aircraft evacuations. The experiment presented in the paper shows how just playing the serious game for a few minutes results in significant increases in user's knowledge and self-efficacy.

Keywords: virtual reality, personal safety, serious games, simulated risk experiences, self-efficacy, risk perception, air passengers, aircraft evacuation

1 Introduction

The field of persuasive technology has only recently started to investigate how virtual simulations of risk experiences can be used to change people' attitudes or behaviors with respect to personal safety [8,21,30]. In general, simulation can persuade people to change by enabling them to observe immediately the link between cause and effect [13]. Moreover, if a virtual risk experience is interactive, it can exploit operant conditioning, by allowing the user to choose his/her behaviors in the virtual experience and providing immediate feedback by showing the positive consequences of recommended behaviors and the negative consequences of dangerous behaviors. Those consequences can be simulated in vivid and memorable ways through visual and auditory stimuli: in this way, the simulation can include affective aspects, which contribute significantly to determine risk perception [28].

The experiments on persuasive virtual experiences of risk carried out so far have focused on measuring their effects on attitudes towards global climate change [21], information search and coping intentions towards flood risks [30], perception of fire risks in buildings [8].

In this paper, we aim at advancing the investigation of virtual risk experiences in different directions. First, we extend the study of their effects to self-efficacy, which is in general an important predictor of future performance [3]. In the specific case of virtual risk experiences, self-efficacy is important also for an additional reason. These experiences can be threatening, and protection motivation theory (PMT) [25] points out how the consideration of self-efficacy is necessary for the success of persuasion attempts which inform people about the negative consequences of given actions on their health. Indeed, if the persuasive attempt threatens the individual, but does not make her feel capable of performing the recommended actions, then PMT predicts that, instead of being persuaded, she will try to reduce the negative emotions induced by threat, e.g. through risk denial and defensive reactions.

Second, we increase the interactivity of the simulated experience with respect to previous studies, by designing and implementing a full serious game (i.e. a videogame to further training and education objectives [31]), in which the user can experiment the whole range of possible (right or wrong) actions typical of the considered risk experience, making progress towards game level completion when she chooses the right ones. In this way, the user can acquire knowledge about several aspects of her personal safety, and we thus investigate also effects of the virtual experience on user's knowledge.

Third, we focus on educating passengers about their personal safety in aircraft evacuations, an important problem to which serious games and persuasive technology have never been applied before.

The paper is organized as follows. In Section 2, we discuss in detail the need for more persuasive approaches to passengers' education in aviation safety, by examining the limitations of the currently employed solutions and motivating our proposal. Section 3 illustrates the importance of the self-efficacy construct in the domain of safety, and describes the persuasive goal and target behavior we consider. In Section 4, we present the serious game we have implemented. Section 5 and 6 respectively present the experimental evaluation and the obtained results. Section 7 concludes the paper and introduces future work.

2 Aviation Safety and Passenger Behavior: a need for more persuasive approaches

Fast and safe evacuation of aircrafts during emergencies is a fundamental aspect of aviation safety. The need for high evacuation efficiency is explained by the fact that the aircraft cabin becomes an unsurvivable environment in about two minutes since fire erupts [22].

Unfortunately, incident and accident reports describe a wide range of inappropriate behaviors by air passengers during emergency situations and aircraft evacuations that jeopardize their and others' survival. For example, in a large safety study conducted by the NTSB [23] which interviewed 457 passengers who have been involved in emergency evacuations, a large number of them (about 50%) admitted to try bringing their luggage with them during the evacuation, thus slowing down the process. Another typical passengers' error is to engage in competitive behaviors with other passengers such as pushing or trying to jump over rows of seats, which can make the evacuation chaotic and considerably slow it down. Additional issues concern lack of knowledge and ability, e.g. not going for the closest emergency exit, not being able of opening doors, moving in smoke instead of crawling below it, trying to carefully sit or to walk on the emergency slide instead of jumping and then sliding.

The primary purpose of aviation safety education is to provide airline passengers with accurate cabin safety knowledge and to cultivate positive passenger attitudes to appropriately affect passenger behavior when an emergency occurs. As pointed out in the study conducted in [7], the level of aviation safety education an airline passenger has does affect her knowledge, attitudes and behaviors. Safety awareness can lead passengers to efficient behaviors and being responsible for their own safety; therefore, improving passenger safety education will increase the probability of their survival in an emergency [22,26].

Education and training is also important because stress and negative affect in a real emergency, combined with lack of knowledge about suitable behaviors, produces in some passengers a "cognitive paralysis" phenomenon, where people do not take any action at all, leading to fatalities in otherwise survivable conditions [18,19]. Therefore, clearly knowing in advance proper safety behavior is a personal protection strategy that would allow each passenger to significantly increase her chance of survival by reducing evacuation time as well as preventing common fatal errors that passengers make due to lack of knowledge. Preparedness also contributes to reduce stress and fear caused by emergency situations, and air passengers need to know the most common potentially hazardous circumstances [12].

Current approaches to passenger education are based on the safety card and flight attendant presentation to which passengers are exposed after they have boarded the aircraft. Unfortunately, these approaches suffer from serious limitations [9]: passenger safety briefings and cards vary greatly; passenger attention to them is poor at best; comprehension of safety cards by passengers is below acceptable limits; studies have shown that typical passengers - even those who report that they pay attention to passenger safety briefings and cards - have little personal knowledge and understanding of the information they have been given to improve their chances of survival. As a result, one of the major reasons for deaths and injuries which could be preventable is that passengers lack preparedness.

The inadequacy of safety cards and briefings is confirmed by passengers who have been involved in real emergencies. For example, Chang and Yang [6] studied the emergency evacuation experiences of 110 passengers involved in a recent serious accident (China Airlines Flight CI-120) to examine deficiencies in passenger safety education: only 14% (respectively 16%) of the passengers found the safety briefing (respectively safety cards) to be useful with respect to their actual need of evacuating the burning aircraft. The majority of passengers said that the received safety information is not sufficient for dealing with emergency escape and they did not feel to have been clearly instructed.

To increase the probability that air travelers will survive in emergencies, substantially improved safety and survival information needs to be implemented and made available through well-constructed passenger education [10]. Different authors agree that airlines should make preflight safety information more appealing and more comprehensible. Cosper and McLean [10] recommend to consider the development of state-of-the-art methods using "creative technologies" for passenger education such as interactive CD-ROMs that could be passed out at airports, air shows, and public events. Chang and Yang [6] suggest that civil aviation authorities should build a safety education exhibit at all airports with safety equipment and emergency use procedures to give passengers an opportunity to use and understand them.

This paper proposes to use serious games as a tool to develop personal safety skills for the following reasons. Compared to safety education exhibits in airports, serious games could be a less costly solution that would also allow passengers to live the simulations discreetly at their homes whenever and how many times they want. Compared to safety cards and video CD-ROMs, training passengers through a game would allow to make safety education materials more attractive and to simulate aircraft emergencies in a much more thorough and realistic way. Indeed, a serious game can immerse its user in aircraft emergency scenarios, where the goal of the game is to survive the emergency and player's survival is strictly dependent on choosing the right actions and taking as less time as possible to complete the evacuation, while staying as far away as possible from danger. To succeed and progress in the game, users would need to improve their decision making in aircraft emergencies, learning to avoid common passengers' errors.

Since people could be willing to devote more attention to a game, and the game could be played at home, the serious game solution could increase exposure time to personal safety content, and promote repetitive rehearsal of safety procedures, which improves retention of knowledge. Moreover, the game 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 (e.g., avoiding smoke, leaving luggage on the plane,…), but would also allow people to familiarize with the different escape routes, seat configurations, location and operation of emergency doors and slides available in the actual aircraft type they are going to fly with.

3 Self-efficacy and Personal Safety

Self-efficacy can be defined as the person's belief in his or her ability to perform a specific behavior [13]. According to Bandura's [2,3,4] Social Cognitive Theory, this belief significantly determines performance outcomes, and different people with similar skills may perform differently depending on variations in their self-efficacy. Research on self-efficacy has shown that the conviction that one can successfully execute the behavior required has a positive effect on performance [3,4].

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 safety (for a summary, see [15,16]). Gaining experience in performing the given behavior is a major factor that contributes to increase self-efficacy [3]. In this sense, the simulations that people can live with a serious game allow them to actually succeed in applying safety knowledge to a virtual life experience, instead of passively listening to traditional safety messages.

Increasing self-efficacy is particularly important in the domain of air passengers' personal safety. Indeed, while in other types of emergencies such as fires in buildings people tend to downplay the severity of the risk to their safety and overestimate their ability to move in the dangerous environment [24], people tend instead to be fearful of even normal flying conditions: estimates of the percentage of population which suffers from fear of flying (which can range from continuous apprehension about flying to severe phobia that can prevent flying) reach up to 40% [29]. Moreover, people have a pessimistic and fatalistic attitude towards aircraft accidents, mistakenly believing that there is little hope of survival. In fact, statistics show otherwise: a survey of commercial jet airplanes accidents [5] indicates that the majority of aircraft accidents is survivable. Another reason why many passengers do not pay attention to safety information is that they tend to shift the responsibility and capability of their safety to the cabin crew [22]. This way of thinking is dangerous because workload and the time constraints of the evacuation makes it impossible for the crew to provide individual assistance to every passenger. Besides, members of the crew could be injured or incapacitated, and this would require passengers to take an even more active role to survive.

Therefore, while increasing perception of risk severity (by also appealing to fear [8]) is a priority for fires in buildings, in the case of aircraft accidents people need instead to be persuaded about their ability to act to increase their likelihood of surviving the emergency.

Of the three possible reasons that prevent desired target behavior highlighted by Fogg's FBM model [14], lack of ability is the one that applies most to the case of response to aircraft emergencies. Indeed, lack of motivation towards proper behavior is unlikely (most people want to survive the emergency), and the lack of a proper trigger can be excluded (clear visual, auditory, olfactory and/or haptic cues present themselves to trigger the behavior). The problem is to persuade passengers that they are capable of acting properly and choosing the right behavior in response to the trigger. A serious game could be an ideal tool to this purpose, presenting the player with the effects of her wrong or right choices in a memorable way.

4 The Serious Game

The serious game we have created allows users to realistically experience aircraft evacuations scenarios of different severity and complexity and try for themselves the effects of taking the different possible actions. We have built an accurate 3D model of the cabin of an Airbus 320 [1], one of the most used aircraft types in service. The simulation includes realistic sounds (e.g., the message that can be heard on the plane to inform passengers they have to brace, some shouts from other passengers,…) and visuals (e.g. smoke and fire effects). Since the main goals of the persuasive game concern increasing knowledge and self-efficacy of passengers, and not risk perception of aircraft emergencies (which as we have seen before people already perceive as serious), we chose not to make the virtual experience too emotionally intense by omitting the portrayal of the character's harm and distress. For example, if the character stands inside toxic smoke, the game level stops and the player is informed about the consequences only textually: she does not see the details or hear the sounds of the character death by suffocation as was instead done in [8], which wanted to increase perception of risk severity about fires in buildings.

The level played by the participant in the study described in this paper concerns an emergency landing in which the player has to face and can learn about several behaviors that greatly affect her personal safety, that is: (i) locating the nearest exits before the emergency occurs, (ii) maintaining the brace position during the emergency landing until the plane comes to a stop, (iii) avoiding taking luggage with oneself during the evacuation, (iv) reaching for the nearest exit, (v) locating an alternative exit in the presence of blocked exits or exits which have been reached by fire, (vi) avoiding competitive actions (pushing or fighting with other passengers, jumping on rows of seats), (vii) crawling below smoke, (vii) jumping on the slides instead of trying to slowly sit on them or to stand on them.

The player can succeed or fail at each of these steps. If she chooses the correct action, then she progresses in the game. When a wrong action is chosen, after learning about its consequences through a short textual description, the player is brought back to the part of the game level in which she took the wrong decision and she has the opportunity to restart from that step, instead of restarting from scratch. As pointed out by [17], this way of organizing a virtual experience can be seen as an application of the reduction and tunneling strategies [13] used in persuasive technology.

To make the game accessible to a wide audience, we did not assume specific experience with videogames or the availability of game input controls: at each moment during gameplay, all actions can be taken by using the four arrow keys and the Ctrl key which is close to them. If the action involves navigation, the four arrow keys control movement, and we have constrained the paths of the virtual character in such a way to prevent the typical situations in which inexperienced players get stuck on 3D objects in the environment (the purpose of the game is indeed to focus on personal safety content and procedures, not on learning to fine control video game characters as in entertainment games). For example, if the character is seated in the aircraft with the belts unbuckled and the player presses the up key, the character will stand up; then, if the player presses the right or left keys, the character will move in a natural way towards the aisle or the window, provided that there are no other passengers which are blocking the path. For additional actions (such as taking luggage, crouching in smoke, trying to push other passengers,…) a semitransparent legend appears in the lowest line of the screen to inform the player about currently available actions and their mappings with keys.

Figures 1 and 2 show examples of respectively the player's character correctly assuming the brace position and a situation in which the player is facing a double threat posed by unusable wing exits and presence of toxic smoke.

Fig. 1. Assuming the brace position.

Fig. 2. Unusable wing exits and toxic smoke threat.

5 Method

5.1 Participants, design and measures

We recruited 26 participants (19 male, 7 female) through personal contact. Participants were volunteer university students who received no compensation and their mean age was 23.85 (SD=2.51).

Video game use was assessed by asking participants to rate their frequency of use of

video games on a 5-point Likert scale (1=never, 5=several hours a day) and their liking of video games on another scale (1=not at all, 5=a lot). Mean frequency of use was 2.50 (SD=1.33) and mean liking was 3.35 (SD=1.09).
We also asked participants about how often they travel by air on a 5-point Likert scale ranging from never to frequent flyer. The mean was 2.38 (SD=1.17). Liking of the flight experience on another scale (1=not at all, 5=a lot) resulted in a mean of 3.04 (SD=1.25).

To measure participants' knowledge about the safety aspects which were dealt with by the game level employed in the evaluation, we used a safety questionnaire with 6 multiple-choice items about (i) proper behavior before an emergency landing, (ii) what to do when the aircraft comes to a stop in the emergency landing, (iii) what to do in case of smoke in the cabin, (iv) usage of slides, (v) behavior in case of exit blocked, (vi) available exits on the aircraft. Four possible answers were presented for each question: three corresponded to typical passengers' errors and one was correct.

To measure subjects' self-efficacy, we designed a 7-item questionnaire, by (i) taking items from well-known self-efficacy questionnaires such as the General Self-Efficacy (GSE) scale [27] and adapting them to our domain description, 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 [20], which leads to build items such as: "I would be able to deal with an emergency evacuation of an aircraft even if there was smoke in the cabin" or "I would be able to deal with an emergency evacuation of an aircraft even if some exits were blocked". Each item was rated by participants on a 5-point Likert scale (1=not at all, 5=very), so the questionnaire assigns a score ranging from 5 to 35 to measure participant's self-efficacy with respect to aircraft evacuation. We assessed internal reliability of the designed questionnaire with Cronbach's alpha test which indicated very high reliability (α =.94).

We also measured risk perception by using the 6 questions employed by [11]: vulnerability to risk was assessed by having respondents rate their vulnerability on 3 items (e.g., "how high do you believe your risk of being involved in an aircraft evacuation is?") and severity of risk on the 3 other items (e.g., "how harmful would the consequences of an aircraft evacuation be?"). Ratings were given on a 5-point Likert scale (1=not at all, 5=very), so the score for each of the two measures ranged from 5 to 15.

Considering the design choices on which the game is based (see Section 4), we hypothesized that playing the game should increase participants' self-efficacy as well as increase their level of knowledge about aircraft evacuations, while it should not heighten their risk perception. As a measure of the change in self-efficacy, we took the difference between its measure taken after and before the game experience, and we proceeded in the same way with risk perception. As a measure of the change in knowledge, we took the difference in the number of wrong answers to the safety questionnaire, taken after and before the game experience.

5.2 Procedure

Subjects were welcomed in the lab and told they were going to try a video game that illustrates procedures of aircraft evacuation. They were 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.

First, subjects filled the demographic, knowledge, self-efficacy and risk perception questionnaires. Then, the experimenter instructed them about the simple game controls and checked if they had understood their usage before allowing them to start playing the game.

Participants played the game on a 30 inches LCD monitor with stereo speakers. The opening screen of the level showed an external view of the aircraft flying low over terrain, with a brief text that introduced the scenario in which the captain had just informed the passengers that he was going to attempt an emergency landing. Then, the viewpoint moved inside the cabin and the game action started with the words "Brace! Brace!" aired on the aircraft public address system. We let participants play until they successfully completed the level, which took between 2 and 3 minutes. After participants completed the level, they answered the knowledge, self-efficacy and risk perception questionnaires for the second time.

6 Results

The means for number of wrong answers and self-efficacy score measured before and after the experience are shown in Figure 3. Differences were analyzed with a non-parametric Wilcoxon test and confirm our hypotheses: after playing the game, there was a statistically significant ($Z=-4.18$, $p<0.001$) decrease in the number of wrong answers which was more than halved, moving from 2.85 ($SD=.93$) to 1.38 ($SD=.98$), and a statistically significant increase in self-efficacy ($Z=-4.27$, $p<0.001$) which rose by 27%, moving from 17.38 ($SD=5.91$) to 22.27 ($SD=5.27$).

The means for risk vulnerability and severity measures before and after the experience are shown in Figure 4. Differences were analyzed with a non-parametric Wilcoxon test and confirmed our hypothesis that risk perception was not going to be heightened: after playing the game, there was no significant change in vulnerability perceptions. However, it is interesting to note that there was a statistically significant ($Z=-2.89$, $p<0.01$), although relatively small decrease in severity, which declined by about 10%, from 3.61 ($SD=.85$) to 3.23 ($SD=.82$). This change might be related to the fact that the simulation was deliberately designed not to be too intense emotionally, but also to the increase in self-efficacy. There was indeed a statistically significant negative correlation between the level of self-efficacy and perception of risk severity, before ($r(26)=-.57$, $p<.01$) as well as after ($r(26)= -.46$, $p=.018$) playing the game.

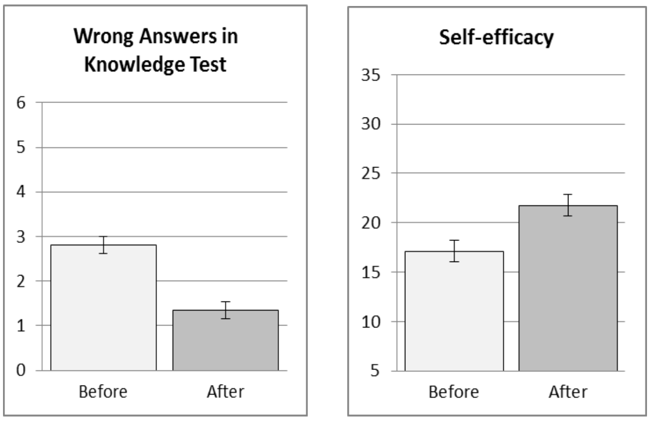

Fig. 3. Mean number of wrong answers and self-efficacy, before and after the experience. Capped vertical bars denote ±1 SE.

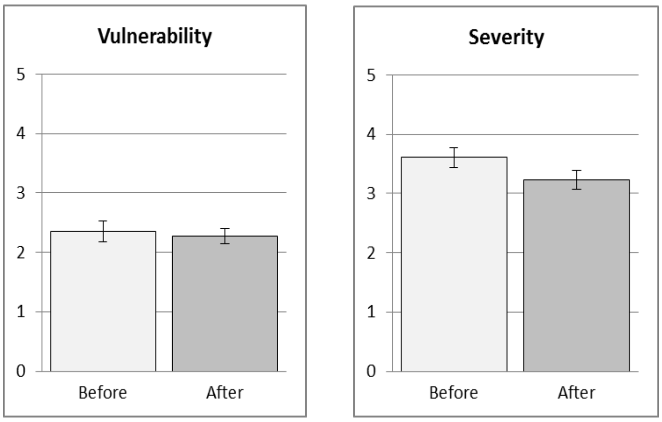

Fig. 4. Risk perception: vulnerability and severity, before and after the experience. Capped vertical bars denote ±1 SE.

7 Conclusions

To the best of our knowledge, our research is the first to study persuasive effects of simulated experiences of risk in the aviation safety education domain. Moreover, with respect to previous studies of simulated risk experiences, we have extended our investigation to important aspects such as self-efficacy and knowledge acquisition.
Overall, the experiment showed that serious games that simulate risk experiences can be a very effective tool for changing attitudes concerning personal safety topics, as well as for learning purposes: just playing a game level for 2-3 minutes resulted in a considerable improvement of users' self-efficacy and knowledge.

The fact that the virtual experience slightly decreased perception of risk severity seems to be consistent with the relation between self-efficacy and severity perception that was pointed in the analysis, but also with the conclusions of our previous study [8] in which we recommended to explicitly depict human suffering and death in emotional ways if the purpose of the simulation is to increase risk perception. To clarify more thoroughly the effects of that recommendation, in future studies we will explore the possibility of making the aircraft evacuation simulation more threatening and increasing negative affect to explore if this would result in more persuasion or could instead be detrimental, resulting in defensive reactions of participants.

To further confirm the more than encouraging results we obtained, we are now planning an experiment with a larger sample of users in which we will contrast the effectiveness of the serious game vs. traditional safety cards and briefings. Although the studies reported in the literature are pessimistic about the effectiveness of safety cards and briefings (as discussed in Section 2), we believe a comparative analysis is needed, also to better quantify the advantages of the serious game solution. Finally, we will consider a longitudinal study to assess attitude and knowledge retention over time as a result of playing the game.

Acknowledgements

Michele Zanolin greatly helped in the development of the game and in setting up the evaluation.

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