Assessing Knowledge Retention of an Immersive Serious Game vs. a Traditional Education Method in Aviation Safety

Luca Chittaro and Fabio Buttussi

Abstract—Thanks to the increasing availability of consumer head-mounted displays, educational applications of immersive VR could now reach to the general public, especially if they include gaming elements (immersive serious games). Safety education of citizens could be a particularly promising domain for immersive serious games, because people tend not to pay attention to and benefit from current safety materials. In this paper, we propose an HMD-based immersive game for educating passengers about aviation safety that allows players to experience a serious aircraft emergency with the goal of surviving it. We compare the proposed approach to a traditional aviation safety education method (the safety card) used by airlines. Unlike most studies of VR for safety knowledge acquisition, we do not focus only on assessing learning immediately after the experience but we extend our attention to knowledge retention over a longer time span. This is a fundamental requirement, because people need to retain safety procedures in order to apply them when faced with danger. A knowledge test administered before, immediately after and one week after the experimental condition showed that the immersive serious game was superior to the safety card. Moreover, subjective as well as physiological measurements employed in the study showed that the immersive serious game was more engaging and fear-arousing than the safety card, a factor that can contribute to explain the obtained superior retention, as we discuss in the paper.

Index Terms—Immersive VR, serious games, user evaluation, knowledge retention, physiological measurements, aviation safety

1 Introduction

Immersive Virtual Reality (VR) has been widely used to train professionals in domains as diverse as medicine (e.g., [1], [2]), firefighting (e.g., [3], [4]) and military training (e.g., [5], [6]). More recently, the field of training is witnessing the introduction of game design techniques in the development of applications, which are often presented as games with a serious purpose (*serious games*). This can be useful to create educational applications of VR that are more engaging, which could make them more attractive to the general public. However, serious games aimed at the general public are now typically limited to desktop VR technology (e.g., only one of the serious games considered in a recent meta-analysis [7] used immersive equipment), but the increasing availability of consumer head-mounted displays could bring a future in which people train and learn by using immersive VR in their homes. However, before enthusiastically embracing this future scenario, studies are needed to assess if immersive serious games aimed at common citizens can actually provide better learning outcomes than the traditional education methods in use today.

Safety education of citizens could be a particularly promising domain for immersive serious games, because people tend not to benefit from current safety materials. For example, although most aircraft accidents are survivable if passengers follow safety procedures [8], most passengers do not pay attention to pre-flight safety briefings and safety cards, which constitute the official safety education approach currently employed in aviation, and the few passengers who pay attention are unable to benefit from such materials, showing an unacceptable level of knowledge acquisition [9]. This situation calls for other solutions that can be more engaging for passengers [10]. In this paper, we propose an HMD-based serious game for educating passengers about aviation safety that allows players to experience a dangerous aircraft emergency with the goal of surviving it. The study we illustrate compares the proposed immersive VR approach with the traditional aviation safety education approach (in particular, the safety card). Unlike most studies of VR for safety knowledge acquisition, we do not focus only on assessing learning immediately after the experience, but we extend our attention to knowledge retention over a longer time span. This is a fundamental requirement, because being able to understand safety procedures is not enough to guarantee survival: people need to retain the procedures in order to apply them when faced with danger. To measure knowledge acquisition and retention, participants in our study answered a knowledge test administered before, immediately after, and one week after trying the experimental condition. We also took subjective as well as physiological measurements to assess engagement, physiological arousal and a specific emotion (fear) that can be evoked by the considered materials.

The paper is organized as follows. Section 2 introduces immersive VR applications for safety education of the general public and discusses the specific issues of engaging users and assessing knowledge retention. Section 3 illustrates in detail the proposed immersive serious game and the choice of immersive hardware. The user evaluation we carried out is described in Section 4, while Section 5 and 6 respectively report and discuss the obtained results. Finally, Section 7 concludes the paper outlining future work.

2 Related Work and Motivations

2.1 Immersive VR for Safety Education of the General Public

Examples of immersive VR for safety training can be found in the literature for different domains, e.g., fire safety [3], [4], pedestrian safety [11], emergency evacuation of buildings [12], traffic safety [13], recognition of risks in work environments [14]. Such applications are often aimed at professionals or are designed in a similar way even if they are meant for the general public. Applications that target professionals benefit from the fact that, for many of their users, it is mandatory to gain, refresh and maintain the knowledge and skills necessary to appropriately operate in the field. Therefore, professionals can be motivated to use the application even if it is not engaging. Unfortunately, this does not hold for the general public, which tends to show lack of interest towards safety education materials, as demonstrated in the aviation safety domain [9], [10]. The exploitation of game design techniques and of immersive hardware could thus be important factors to engage the general public, attracting more attention towards the safety materials and increasing exposure

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to safety knowledge. Unfortunately, despite the adoption of game engines for developing immersive safety training systems for non-professionals (e.g., [12], [13]), existing proposals typically lack engaging elements that are instead central to entertainment games, such as a narrative that includes emotionally intense events and the provision of vivid feedback.

Surprising events, e.g., monsters that suddenly pop out close to the users' avatar in horror games like Resident Evil [15] or Outlast [16], are one of the techniques used to boost user attention as well as create emotions in entertainment games. Another technique consists in showing the consequences of users' actions in vivid ways. This applies to games of different genres, ranging from first-person shooters (like Call of Duty [17] or Battlefield [18], in which players who do not protect themselves from threats see their avatar being harmed, suffering and dying in realistic ways) to adventure and even platform games (like Uncharted [19] and Ratchet&Clank [20], in which players who fail to jump at the right time see their avatars cry, being harmed or die in deep cliffs or poisoned waters).

The use of such techniques, which we explore in this paper, would be valuable in immersive VR experiences too, and not only for increasing engagement. Surprising events have been shown to have a positive effect on knowledge gain [21]. Moreover, work in neuroscience [22]–[24] and psychology [25]–[29] indicates that the emotional intensity aroused by an experience increases memory retention and negative emotional arousal (such as fear) can be especially effective [26]–[28]. Therefore, the inclusion of emotionally intense events and depictions of negative consequences of users' errors typical of entertainment games could promote knowledge retention in VR-based safety education.

2.2 Knowledge Retention

Studies of VR applications for education and training often test knowledge acquisition outcomes only immediately after the virtual experience, without assessing if the acquired knowledge is retained over a longer period of time. More rare studies have included retention, especially with medical applications of VR. For example, Silverstein et al. [1] proposed a teleimmersive VR system for hepatic surgery and evaluated it by administering a test that consisted of 24 basic anatomic and relationship-function questions, before (pre-test), immediately after (post-test) and six months after a 45-minutes session with the system. They found significant improvements in the mean test scores between pre-test and post-test, and complete retention of the knowledge after six months. In [2], a sample of 22 trainees tried a high-fidelity VR simulator to acquire gastrointestinal endoscopy skills under two conditions, i.e., with and without feedback from a supervisor. All subjects completed the procedure on the simulator, repeating an endoscopy task 15 times. Subjects in the group with feedback performed better, while both groups showed no significant degradation in a retention test performed 4-6 weeks after the last repetition. Unfortunately, these studies consider only the VR system and not the educational methods that are traditionally used to acquire the same knowledge. This makes it impossible to conclude that the benefits they find actually improve the existing level of education in the considered domain.

To consider systems aimed at non-professionals, we have to extend our attention to non-immersive VR. A recent meta-analysis involved 69 studies of such virtual experiences to teach science, mathematics, medicine, and other topics to K-12 and higher students [30]. Only a few of these studies included retention tests. More precisely, authors did not find enough studies that included both a test administered immediately after instruction and a test administered after a delay, so they compared the effects of studies assessing knowledge only immediately after instruction with those assessing knowledge only after a delay. The analysis found that students using non-game simulations performed better when the test was administered immediately after instruction rather than when it was delayed. For games, no differences were found between studies that assessed knowledge immediately or after a delay. Finally, an evaluation of two non-immersive safety education games for a very specific target of users, i.e., children affected by fetal alcohol syndrome, involved 32 children who were pretested on verbal knowledge about fire and street safety [31]. Participants played either a fire safety game or a street safety game until mastery. All participants were retested again immediately after playing and one week after, and at both times they showed a significant knowledge gain in the addressed safety topic, although some knowledge loss was found in the 1-week retention test.

As anticipated in the previous section, emotional arousal (especially with negative emotions such as fear) is a factor that positively affects retention, as shown by different studies [22]–[29]. None of these studies employed VR, but some of them used audio-video narratives as experimental materials. An influential work using narratives is the one by Cahill et al. [32]. They exposed participants to two narratives accompanied by photographic slides. The narratives concerned a day in the life of a woman and her young child and were organized in 12 steps: the first four steps of the two narratives were identical and emotionally neutral and the last three were nearly identical and again emotionally neutral. The central part was instead traumatic in one narrative (the boy is hit by a car and hospitalized with serious injuries) and remained more emotionally neutral in the other condition (the boy watches a disaster drill practiced by an hospital staff with actors and make-up artists). In an unannounced 1-week retention test, participants remembered the more emotionally arousing narrative in more detail than the other narrative. Neuroscientists hypothesized as an explanation for these kind of results that the increase in norepinephrine (a stress hormone) in the amygdala (a brain region important for emotional arousal) produced by arousal is responsible for enhanced memory consolidation [24]. To test this hypothesis, Cahill et al. [32] repeated their 1-week memory retention study by manipulating norepinephrine, showing that giving a norepinephrine blocker drug to participants eliminates the advantage in 1-week retention of the arousing narrative, while the significant advantage of the arousing narrative over the more neutral one remains intact when giving a placebo drug to participants.

As a summary of this section, the effectiveness of immersive VR applications that exploit emotionally engaging game design techniques for educating the general public about safety is a topic that needs to be studied. Moreover, its study should include measures of engagement and emotional arousal as well as compare knowledge retention with traditional educational methods. The evaluation we describe in this paper pursues all these goals.

3 The Immersive Serious Game

The immersive serious game we developed allows players to experience a full emergency landing and evacuation of a commercial aircraft. In particular, the scenario we study in this paper concerns a water landing (*ditching*, in aviation terminology) and evacuation of an Airbus 320 [33], one of the most used aircraft types in service. The scenario is inspired by the real accident occurred to US Airways flight 1549 [34], which struck a flock of large birds a few minutes after take-off and, as a consequence, lost thrust in both engines and was forced to ditch on a river.

To make the game engaging and emotionally arousing, we introduced the elements typical of entertainment games summarized in Section 2.1, modeling surprising events and vividly depicting the consequences of players' errors. Moreover, to choose among different contextual actions, we provided players with an interface inspired to action-adventure games such as Heavy Rain [35]. In this section, we present in more detail each of these aspects, and we further motivate the choice of immersive hardware for the game.

3.1 Narrative and Players' Actions

This section describes all main events in the game narrative and their relations with the different possible (right or wrong) actions that players can perform at each time. In general, choosing a correct action makes players progress towards survival, which is the ultimate goal of the game, while the choice of a wrong action or the omission of a right one triggers a negative feedback and a recommendation about proper behavior. More precisely, if in the real world the specific error cannot (or is very difficult to) be corrected once made (e.g., opening an exit door that is under water, inflating the life vest while seated,…), the game shows its negative consequences and pauses. A fading effect is applied to the scene and a brief textual recommendation is superimposed for 7 seconds (see example in Figure 1d). Then, players are brought back to the point in the narrative where they took the wrong decision and restart playing from there. On the contrary, if in the real world the specific wrong action can be quickly corrected (e.g., if passengers make the error of taking luggage with them and then realize that it slows down evacuation, they can leave it in a place where it does not affect safety), then the immersive experience is not interrupted and nearby passengers or flight attendants verbally give the recommendation to the player. However, if players still do not comply with the safety recommendation (e.g., they still keep their luggage), then after 10 seconds the game treats the error in the same way as it does with irreversible errors.

The narrative starts with the player seated in the aircraft some minutes after takeoff and evolves following this sequence of steps:

1. The aircraft is flying normally and passengers look calm (Figure 1a). Normal engine sound and people chattering can be heard.
2. The aircraft suddenly shakes and a loud sound is heard (strike with flock of birds). Flames and smoke start coming out from engines and the player can see them by looking out of the window (Figure 1b).
3. The captain announces that there is an issue with the engines and orders passengers to fasten seat belts. If the player does not fasten seat belts promptly, a sudden instability of the aircraft makes the avatar hit the forward seat with the head and blood spatters on the eyes (Figure 1c), then a textual recommendation (Figure 1d) is shown and the player has to repeat step 3.
4. The captain makes a second announcement, asking passengers to prepare for an emergency landing by assuming the brace position. Flight attendants keep shouting "Brace!" until the aircraft hits water. If the player does not assume the brace position and keep it until the aircraft comes to a stop, the avatar gets injured (in the same way described in the previous step) and the player has to repeat step 4.
5. After the water landing, injuries and blood stains can be seen on the skin of other passengers and their faces become worried and fearful (Figures 1e and 1f). The crew gives evacuation orders, and the player can perform different actions: unfasten seat belts, take and wear the life vest, and stand up. If the player stands up without the life vest, the nearby passenger reminds him/her to wear it before leaving the seat (Figure 1e). If the player persists in not wearing the life vest, then a textual recommendation is shown and the player has to repeat step 5. After the player has donned the life vest, the inflate action becomes available and remains so until the life vest is inflated: performing such action is correct only at step 10, while inflating the life vest at any other step will result in a recommendation and a restart from the instant before the life vest was inflated.
6. The passenger seated near the player moves away and the player can reach the aisle. When the player is close to his/her seat in the aisle, taking luggage is a possible action. If the player chooses it, the avatar movement becomes slow and other passengers complain about the slowdown of the evacuation, telling the player to drop luggage. If the player does not drop it, then a textual recommendation is shown and the game restarts from the instant before luggage was taken.
7. The player moves towards an exit. If (s)he goes in the direction of the farther exits, a passenger blocks the way (Figure 1f) telling the player to go towards the closest exits (rear exits).
8. The player reaches the rear galley, where the exit doors are under the water level and water is slowly entering the aircraft. If the player opens the exit door, water floods the galley very rapidly and the avatar drowns (Figure 1g), then a recommendation is shown and the player has to repeat step 8. While the avatar drowns, all sounds become muffled and suffocation sounds can be heard.
9. The player moves towards the front of the aircraft. The overwing exits cannot be used because many passengers are standing on the wings of the aircraft, blocking the flow of passengers who are trying to use those exits (Figure 1h). Two flight attendants from the front of the aircraft call the remaining passengers there (Figure 1i).
10. When the player reaches a front exit, the two flight attendants order to reach the bottom of slide rafts and seat down there. The player leaves the aircraft, but if (s)he forgets to inflate the life vest now, the avatar unexpectedly slips, falls into water and drowns, then a recommendation is shown and the player has to repeat step 10.
11. The player has to seat at the bottom of the raft (to avoid slowing down the passengers who are following behind). If (s)he does not, the flight attendants shout at him/her to seat at the bottom. The evacuation completes successfully when the player complies (Figure 1j).

3.2 Choice of immersive VR set-up: motivations

The game is meant for use with a stereoscopic HMD with 3-DOF head tracking by users seated on a swivel chair that allows them to turn over 360 degrees, determining the direction in which they want to move. The choice of this immersive VR set-up was based on the following benefits that it could offer over a desktop VR set-up. Two benefits concern interest in trying the safety materials and attention paid to them, which are major issues for aviation safety as seen in Section 1. While a well-designed desktop serious game might already generate more interest than traditional safety materials, an HMD-based version introduces an additional novelty factor that could further motivate people to try the serious game. For example, Litwiller and LaViola [36] showed that simply using a 3D stereo display to play commercial video games is sufficient to make people prefer the played games over their traditional versions, even if the games are not designed with 3D stereo in mind. Adding more immersive hardware (such as head tracking and HMDs) can further increase user's interest and engagement. For example, Arthur, Booth, and Ware [37] showed that head-tracking created in users a more compelling 3D perception than stereo viewing alone.

Additional benefits concern quality of learning itself. Dede et al. [38] suggest that HMD-based, 3D multisensory representations can facilitate development of more complete, accurate and causal mental models in users than 2D representations, and present an experiment that supports the claim by comparing the two alternatives in learning scientific concepts. Winn et al. [39] showed that interacting with an immersive HMD-based educational environment helps learners understand complex real-world phenomena more than interacting with an equivalent desktop environment. Greater sense of presence, attributed to reduction of distraction and more engagement in the experience, was reported as a predictor of such better results. Bowman et al. [40] underlined that another important improvement of HMD-based educational environments is that they allow learners to better understand the relationships between spatial information and abstract information associated to it.

Finally, unlike traditional viewpoint control in desktop serious games, the solution we have developed exploits head-tracking to allow players to look around in the environment and requires them to change their body orientation (by rotating on the swivel chair) to define the direction in which they want to move in the environment. Since research supports the contribution of proprioception in acquiring spatial knowledge (see [41] for a detailed account), presenting a view of the environment that changes based on head and body orientation creates a context that is more similar to that of real-world spatial knowledge acquisition. Supporting a process of spatial knowledge

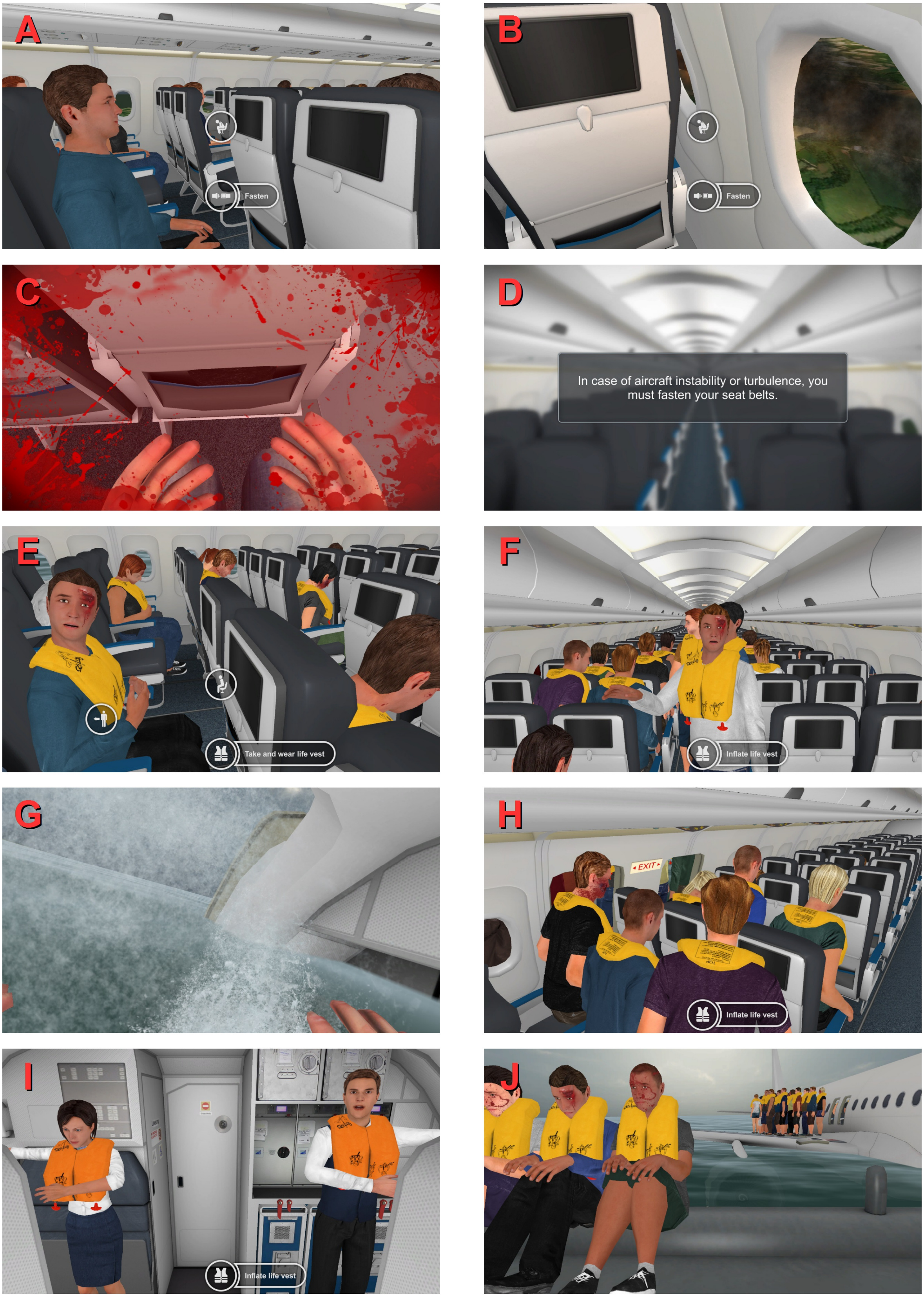

Fig. 1. Some situations experienced by players in the immersive game: a) aircraft cabin and passengers before the bird strike, b) smoke and flames coming from the engine as seen by looking out of the window, c) blood spatters on the eyes in case of head injury, d) a textual recommendation displayed after an irreversible player's error, e) passenger seated close to the player reminds to wear the life vest, semitransparent icons indicate three contextually available actions, “Take and wear life vest” is the currently selected action, f) a passenger indicates the closest exit to the player, g) drowning after opening a door under the water level, h) passengers blocked while trying to use the overwing exits, i) flight attendants calling passengers to the front exits, j) passengers on rafts and wings at the end of the evacuation.

Fig. 2. The Nintendo Nunchuck controller for action selection.

acquisition consistent with that used by human cognition to learn spaces (which includes proprioceptive cues) is particularly important for aircraft environments. Indeed, aviation emergencies require very fast evacuation times, because the aircraft cabin can become an unsurvivable environment in about two minutes, e.g., due to fire [42]. With such strict time constraints, the better passengers have learned the spatial structure of the aircraft and how to orient themselves in it, the more efficiently they can evacuate it, increasing their chances of survival.

For action selection in the studied serious game, we used a Nintendo Nunchuck as a hand controller (Figure 2). To move in the direction they are currently facing, players hold the Z button on the Nunchuck. Semitransparent white icons superimposed on the scene (see example in Figure 1e) contextually appear to show the other currently available actions. Players select icons using the joystick on the Nunchuck, and a brief textual description of the action is displayed near the currently selected icon (see Figure 1e). By pressing the button C on the Nunchuck, the selected action is performed.

4 User Evaluation

To evaluate the possible effectiveness of the immersive serious game, we carried out a between-groups study. Half participants (Immersive Game group) tried the game, while the other half (Safety Card group) tried instead a safety card that presented the same safety knowledge. Our hypotheses were: (i) since both materials (game or card) expose participants to the same safety knowledge, the two groups should both show a knowledge gain immediately after usage, (ii) the immersive game should be more engaging as well as emotionally arousing than the safety card, (iii) using the immersive game should result in more knowledge retention over time than using the safety card, as the studies that relate emotions (especially negative emotions such as fear) and memory would suggest (see Section 2).

4.1 Materials

The immersive serious game was implemented using the Unity 4.5 game engine, and run on a PC equipped with a 2.67 GHz Intel i7 processor, 6-GB RAM, and an NVidia GTX 480 graphic card. The HMD was a Sony HMZ-T1 HMD (two OLED displays each with 1280x720 resolution, 45° field-of-view) and the 3-DOF sensor was an InterSense InertiaCube3 (A, Figure 3). The Nintendo Nunchuck controller (B, Figure 3) was wirelessly connected to the PC using a Bluetooth adapter. The immersive serious game ran at an average of 50 frames per second. The graphic output of the PC was displayed also on an LCD display (C, Figure 3) to allow the experimenter see participants' actions in the game.

Both the immersive serious game and the safety card provided participants with the following safety knowledge: (i) fasten seat belts as soon as the airborne plane shows signs of instability or turbulence, (ii) assume and keep the brace position during all the emergency landing until the plane comes to a stop, (iii) the life vest is under the seat, (iv) wear the life vest before leaving the seat, (v) inflate the life vest only when you are leaving the aircraft, (vi) leave any luggage on the plane, (vii) reach for the exit closest to you, (viii) do not open an exit door when it is under the water level, (ix) locate an alternative exit when the chosen exit cannot be used, (x) go towards the bottom of the slide raft before sitting on it (to avoid slowing down the passengers who are following behind).

The safety card was A4-sized, printed in color. The instructions and pictorials in the card were those that provide the above listed knowledge in the Airbus 320 safety card currently employed by one of the largest world airlines.

In both experimental conditions, physiological data was acquired by using a Thought Technology Procomp Infiniti encoder that was placed in a pouch attached to the back of the swivel chair (D, Figure 3). An electrodermal activity (EDA) sensor and a photoplethysmograph (PPG) sensor applied to fingers of the non-playing hand (E, Figure 3) were connected to the encoder. Data acquired by the encoder was stored on a second PC, connected to two displays: (i) an LCD display (F, Figure 3) used by the experimenter to monitor physiological data recording, (ii) a 30" LCD display (G, Figure 3) used to show an initial video to participants (see Section 4.4).

4.2 Participants

The evaluation involved a sample of 48 participants (26 M, 22 F). Participants were volunteers who received no compensation and were recruited through personal contact. They were graduate and undergraduate students enrolled in different programs as well as people from other occupations. Age ranged from 18 to 38 (M=24.19, SD=4.35).

We assessed individual differences in frequency of air travel by asking participants to count their number of flights in the last two years, as in [9]. 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 four flights. Answers ranged from 0 to 8 (M=2.25, SD=2.69).

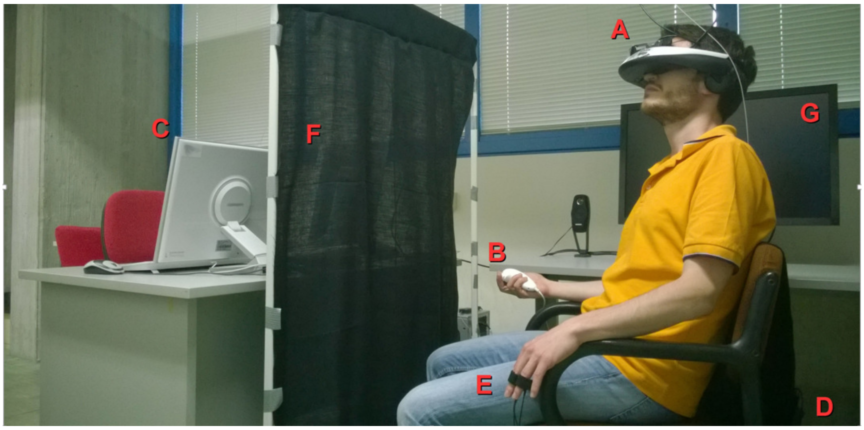

Fig. 3. The experimental setting.

We also asked participants to rate their frequency of use of video games 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). Twelve users reported they never play video games, 11 play less than once a month, 8 play once or several times a month, 8 play several times a week, and 9 play every day.

Since individual participants' sensitivity to the considered fear-arousing situation is known to play a mediating role in studies of emotional arousal, we assessed pre-existing individual differences to properly control for them in the analysis of players' emotion and arousal. To this purpose, we used the 32-items Flight Anxiety Situations questionnaire (FAS) developed by [43]. 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. [44] 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 score was 102.42 (SD=22.48) for the first group, while it was 39.84 (SD=11.92) for the second group. In our sample, the FAS score ranged from 34 to 101 (M=60.27, SD=16.27).

Participants were assigned to the two conditions in such a way that: (i) the proportion of men and women was identical (13M and 11F in each group), since gender-balanced groups are particularly important in studies where fear is involved (see [45] 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 air travel, frequency of video game use, and fear of flying. Independent samples t-tests confirmed the lack of significant differences between the two groups for the four demographic variables.

4.3 Measures

4.3.1 Knowledge

To measure participants' knowledge, we prepared a test with 10 questions, one for each of the 10 safety concepts described in Section 4.1. More specifically the 10 questions were: what to do in case of in-flight aircraft instability; what to do in preparation for impact; where the life vest is located; what to do before leaving the seat; when the life vest has to be inflated; what to do with one's luggage; which exit should be the first choice for evacuation; when it is not possible to use an exit; what to do if the chosen exit cannot be used; what to do after reaching a raft. To avoid suggesting possible answers (e.g., as a multiple-choice questionnaire would do), participants were asked to answer the questions orally. 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.

We administered the knowledge test three times: before trying the safety material (pre-test), immediately after trying it (post-test), and a week later (retention-test). Mean pre-test score showed that, before trying the experimental conditions, participants were able to answer correctly only about half of the questions (M=5.40, SD=1.69). An independent samples t-test showed no significant differences in initial knowledge between the two groups.

4.3.2 Self-Reported Fear

Following [46], we measured participants' level of fear aroused by the experimental conditions by asking them to rate six mood adjectives (scared, tense, anxious, uncomfortable, nervous, fearful) about how the tried condition made them feel. The adjectives were rated on a 7-point Likert scale (1=not at all, 7=very). The six ratings were averaged to form a reliable scale, Cronbach's alpha=0.97.

4.3.3 Self-Reported Engagement

To measure the level of engagement experienced by participants, we administered a questionnaire that asked them to think about the experience they just tried and rate their level of agreement on a 7-point Likert scale (1=not at all, 7=very) about six statements, worded in such a way that they could apply to both the immersive serious game and the safety card. The six items were: "It was boring", "It was engaging", "It was fun", "The depicted situation looked real", "I lost track of time", "I felt immersed in the depicted situation". After inverting the scale of the first item, the six ratings were averaged to form a reliable scale, Cronbach's alpha=0.83.

4.3.4 Physiological Arousal

To record participants' physiological data, the EDA sensor was placed on the participants' intermediate phalanges of the middle and little fingers, and the PPG sensor was placed on the distal phalanx of the index finger of the non-playing hand.

From the EDA signal, we extracted skin conductance level (SCL) through decomposition analysis [47]. SCL is increasingly used in studies of fear and anxiety in VR, e.g., [48]–[51]. SCL is the more stable of the two components of the electrodermal signal and is typically used to measure the level of EDA during a given period of time [52].

From the raw blood volume pulse (BVP) signal provided by the PPG sensor, we calculated BVP amplitude (BVPA), which is the distance between local maximum and minimum of the signal. BVPA can be employed as an index of sympathetic arousal: a decrease in BVPA indicates increased arousal.

Before participants tried the safety materials, we measured their physiological 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 [52].

4.4 Procedure

Participants were told that the goal of the experiment was to evaluate a safety material that shows what to do in an aircraft emergency landing and evacuation. Consent for participation and for recording physiological data and verbal answers to the knowledge test was asked. Participants were also informed that they were going to be contacted again a week later for an additional questionnaire (without specifying what those further questions concerned), and that they could refrain from continuing the experiment at any time without providing a reason to the experimenter. After participants gave their consent to participate in the experiment, they filled the initial questionnaire (age, frequency of air travel, frequency of game use and FAS) and verbally answered the knowledge questions for the pre-test.

Participants in the Immersive Game group were invited to wear the HMD and were helped by the experimenter to adjust it until they could see well and feel comfortable with it. Then, the experimenter gave participants the Nunchuck controller and explained the controls. Participants used the controller with their preferred hand and tried the controls on a simple virtual environment (an empty room with a lamp that could be switched on) until they had fully understood how to navigate and select actions. More precisely, the experimenter invited each participant to look around, move forward, briefly explore, select actions, and finally reach the lamp and turn it on. All participants quickly understood the controls. Then, the HMD was removed to proceed with the physiological baseline recording.

In both experimental conditions, the experimenter applied EDA and PPG sensors on the fingers of participants' non-playing hand, and then invited participants to relax for two minutes, during which they could watch a video (on a 30" LCD display, G in Figure 3) with relaxing images and music in a dim light, or simply close their eyes and listen to the music. While participants relaxed, the experimenter recorded their baseline physiological values.

After baseline recording, the experimenter invited participants to try the safety material assigned to them. 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 using the safety material. In the Safety Card group, the experimenter gave the safety card to participants, while in the Immersive Game group, the experimenter helped participants in wearing again and adjusting the HMD, then the game was started.

After the experimental condition, physiological sensors were removed and participants filled the questionnaires about fear and engagement. Then, they verbally answered the knowledge questions for the post-test.

A week after the test, the experimenter contacted the participants again to verbally ask the knowledge questions for the retention-test.

5 Results

5.1 Knowledge

Knowledge scores were submitted to a 2 x 3 mixed design ANOVA, in which group served as the between-subjects variable, and time of measurement (before, immediately after, and a week after) served as the within-subjects variable. Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2(2)=9.00$, $p=0.01$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon=0.85$). Statistically significant results revealed a main effect of time of measurement, $F(1.69, 77.88)=119.17$, $p<0.001$, $\eta_p^2=0.72$, and a group by time of measurement interaction, $F(1.69, 77.88)=6.26$, $p=0.005$, $\eta_p^2=0.12$.

Following [53], we thus proceeded with the analysis of simple main effects to investigate the interaction by testing the effects of time of measurement separately for each group and the effects of group separately at each level of time of measurement. To test the effects of time of measurement separately for each group, we carried out a one-way repeated measures ANOVA, followed by pairwise comparisons using Bonferroni test. In the Safety Card group (Figure 4), the mean pre-test knowledge score was 5.54 (SD=1.72), the mean post-test score was 8.13 (SD=1.30), and the mean retention-test score was 7.29 (SD=1.63). The analysis revealed a statistically significant difference, $F(2, 46)=43.08$, $p<0.001$, $\eta_p^2=0.65$. All three pairwise comparisons with Bonferroni test were also significant ($p=0.008$ for the difference between post-test and retention-test, and $p<0.001$ for the other two pairs). In the Immersive Game group (Figure 4), the mean pre-test knowledge score was 5.25 (SD=1.67), the mean post-test score was 8.42 (SD=1.06), and the mean retention-test score was 8.42 (SD=0.88). Repeated measures ANOVA with Greenhouse-Geisser correction (Mauchly's test $\chi^2(2)=7.12$, $p=0.03$, $\varepsilon=0.78$) revealed a statistically significant difference, $F(1.57, 36.04)=82.21$, $p<0.001$, $\eta_p^2=0.78$. In pairwise comparisons, the difference between pre-test and both post-test and retention-test was statistically significant ($p<0.001$), while no statistically significant differences were detected between post-test and retention-test in the Immersive Game group.

To test the effects of group separately at each level of time of measurements, we performed a between-subjects ANOVA for each of its three levels. We found no statistically significant difference between the two groups at pre-test and post-test times of measurement, while we found a statistically significant difference at retention-test time, $F(1, 46)=8.87$, $p=0.005$, $\eta_p^2=0.16$, with a higher retention in the Immersive Game group (M=8.42, SD=0.88) than in the Safety Card group (M=7.29, SD=1.63).

5.2 Self-Reported Fear

Differences in self-reported fear (Figure 5) were analyzed with a between-subjects ANCOVA, controlling for participant's fear of flying. The difference between the two groups was statistically significant, $F(1, 45)=24.67$, $p<0.001$, $\eta_p^2=0.35$. Fear aroused by the immersive serious game (M=3.01, SD=1.64) was higher than the safety card (M=1.40, SD=0.50).

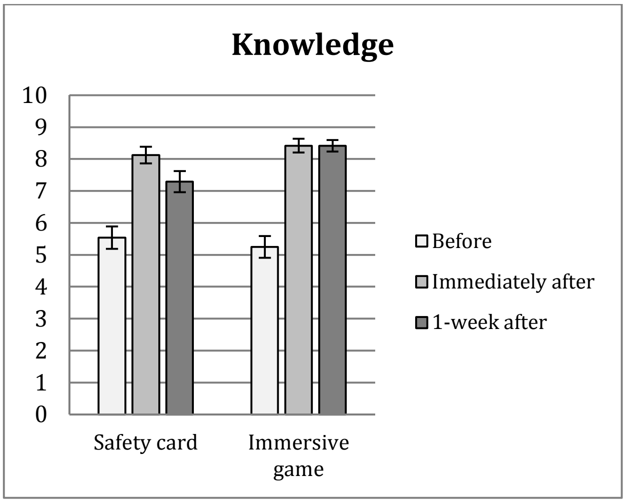

Fig. 4. Means of the knowledge test administered before, immediately after, and a week after the experimental condition. Capped vertical bars indicate ± SE.

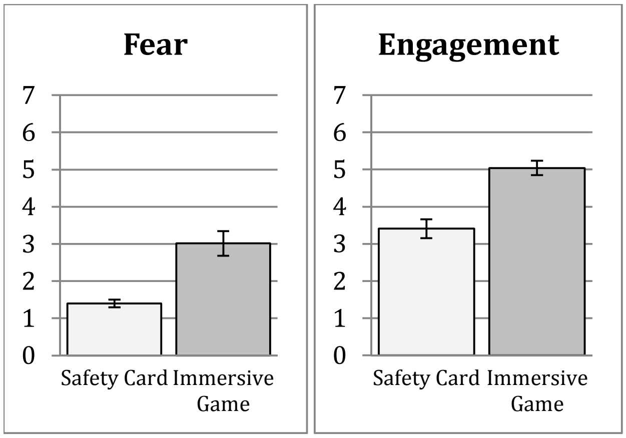

Fig. 5. Means of self-reported fear and engagement. Capped vertical bars indicate ± SE.

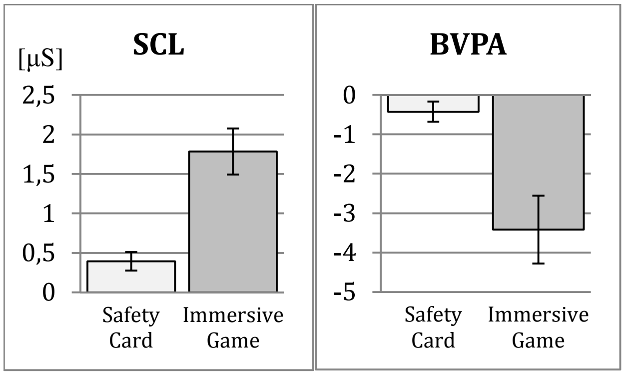

Fig. 6. Mean change in SCL and BVPA with respect to baseline values. Capped vertical bars indicate ± SE.

5.3 Self-Reported Engagement

Differences in self-reported engagement (Figure 5) were analyzed with a between-subjects ANCOVA, controlling for participant's fear of flying. The difference between the two groups was statistically significant, $F(1, 45)=25.92$, $p<0.001$, $\eta_p^2=0.37$. The immersive serious game was more engaging (M=5.04, SD=0.94) than the safety card (M=3.41, SD=1.24).

5.4 Physiological Arousal

After baseline subtraction, we ran two separate between-subjects ANCOVAs with respectively SCL and BVPA as the dependent variable, controlling for fear of flying. The difference in SCL between the two groups was statistically significant, $F(1, 45)=19.58$, $p<0.001$, $\eta_p^2=0.30$, and the mean increase in SCL with respect to baseline values was 0.39 μS (SD=0.58) for the Safety Card group, and 1.78 μS (SD=1.42) for the Immersive Game group, pointing out higher arousal in the Immersive Game group (Figure 6).

The difference in BVPA between the two groups was statistically significant, $F(1, 45)=11.06$, $p=0.002$, $\eta_p^2=0.20$, and the mean change in BVPA with respect to baseline values was -0.43 (SD=1.25) for the Safety Card group, and -3.42 (SD=4.21) for the Immersive Game group, pointing out higher arousal in the Immersive Game group (Figure 6).

6 Discussion

The results of the experiment confirm our hypotheses. Considering the knowledge gain between pre-test and post-test, the safety card and the immersive serious game were both effective and produced similar results. In the study, participants of both groups were invited to spend as much time as they wanted in the experimental condition and the similar knowledge they demonstrated immediately after trying the condition indicates that they paid attention to the materials. It must be noted that in non-experimental settings most passengers unfortunately do not pay attention to safety cards [9], so a game-like, more engaging educational method might have the advantage of being more attractive. While our results promisingly show that users rated the game as more engaging than the card, our evaluation was conducted in the lab so a different study would be necessary to compare the level of attractiveness of the immersive game with respect to the card in more natural settings.

The learning outcome in which the immersive game proved to be superior to the safety card is retention, a fundamental requirement for survival in real emergencies. Indeed, the retention-test administered to participants one week after the experimental condition showed that the immersive serious game is more effective than the safety card in obtaining retention of the safety knowledge. The advantages of the immersive serious game are further highlighted when considering the difference between post-test and retention-test: while participants using the game did not suffer loss of knowledge between post-test and retention-test, participants who used the safety card suffered a statistically significant knowledge loss.

A factor that can contribute to explain such important advantage of the immersive serious game is the relation between emotionally arousing experiences and retention pointed out by neuroscience and psychology research summarized in Section 2. Our immersive serious game was indeed significantly more engaging and more fearful than the safety card in self-report questionnaires. Moreover, it produced consistent and statistically significant higher emotional arousal, physiologically measured in terms of both SCL and BVPA. Unlike traditional theoretical studies on the relations between emotion and memory, our study included an immersive VR condition. We showed that the obtained results are consistent with those of studies employing traditional stimuli: the more emotionally arousing experience (immersive game) in our study produced stronger, more difficult to forget memories of the safety concepts than the less emotionally arousing experience (safety card) that provided participants with the same safety concepts.

A limitation of the reliance on fear in the immersive game is that, while the game can be effectively used for training passengers on the ground (including in home contexts), arousal of fear in the simulated emergency makes the game content not suitable as on-board content for passengers' seat screens, because many passengers might find it inappropriate to see such explicit depictions of aircraft accidents and their consequences while they are seated on a plane. This issue generally affects any content that is provided by in-flight entertainment systems: while people can watch and enjoy movies and documentaries that depict aircraft disasters when they are at home and in theatres, such materials are usually not included in the in-flight entertainment programs of airlines. For this reason, our project is proceeding over two parallel lines: for ground use, we are developing the serious game of which this paper described a level, while for on-board use we are creating another game that re-uses the same 3D models and aircraft environments but relies on a different design of the virtual experience. In particular, the on-board system appeals to different emotions (e.g., using humor, the avatar can make funny remarks or actions in response to player's right or wrong choices) and takes inspiration from other game genres (e.g., a puzzle game with ability and time challenges in which the player has to find the routes from his/her own seat to the different exits that can be opened), without fearful depictions of emergencies and their consequences.

In addition to improving knowledge retention and engagement, using the fear-arousing serious game on the ground could possibly have an interesting effect on passengers' fear of flying that has not been explored in this paper. Immersive VR has been indeed shown to be effective to treat anxiety and phobias through prolonged exposure to virtual versions of the feared situations (VRET, Virtual Reality Exposure Therapy), see [54] for a systematic review and [55] for a meta-analysis of VRET studies. A similar approach has been used also for training purposes to help people develop better coping strategies and learn to control emotional reactions when facing fearful, life-threatening situations they could encounter in the real-world (SIT, Stress Inoculation Training), see e.g., [56]. Therefore, repeated exposure to fearful virtual experiences of aircraft emergencies, combined with performing the right actions to survive in such situations, could make passengers less fearful of flying in general as well as less anxious and stressed in the event of an emergency during their real flights. Of course, although VRET and SIT theories and clinical studies could lead to optimism about the validity of this conjecture, specific studies are needed to test it. We are taking into account such possibility in our further development of the game, by introducing a game control to allow players to adjust how scary the game should be, so that they can follow a progressive exposure process, possibly in a self-paced way.

In our experiment, we observed that participants spent different times to examine the two types of safety materials (M=93.8 s, SD=48.6, for the Safety Card; M=321.9 s, SD=83.0, for the Immersive Game). A time difference between the two types of materials is inevitable, because of the way they provide users with the ten safety recommendations. While the pictorials of the safety card directly provide the recommendations, the immersive game embeds the recommendations in a full narrative of an entire aircraft accident (from its in-flight inception up to the final moment in which the passenger is safe on the raft) that requires time to develop. Moreover, the interactive nature of the game experience introduces additional times, because the game waits for the user to take actions in order to proceed with the next step in the narrative, e.g., users have to actually move in the virtual environment to reach an exit or they have to unfasten the seat belts before they can be able to stand up from their seat. Showing the negative consequences of wrong actions (such as the drowning scene) adds further time. Therefore, although the two types of safety materials ultimately provide the same recommendations, the game needs more time to create an experience that could be immersive and engaging for players and to allow them to act in the virtual environment and see the consequences of their actions. The latter aspect can also be a factor that contributes to make the game approach more effective, because enabling people to observe immediately the link between cause and effect through simulation can persuade them to change their attitudes and behavior [57].

The considerations we made in this paper about the choice of using immersive VR hardware for our game can apply more generally to the field of serious games. User's engagement and emotion arousal are essential features that allow designers to turn a simulation into a game [58], making it more attractive to the public, and serious games strive to create them. The adoption of immersive VR hardware (currently rare in the serious game community) can be one of the factors that help in facing this issue, along with other factors which concern instead game design, e.g., in this paper we explored emotionally intense events and the provision of vivid visual and auditory feedback. As we have seen in Sections 2 and 3.2, immersive VR hardware could also improve the quality of the learning supported by serious games, and emotion arousal can improve retention of the learned concepts. However, a major limitation of using immersive VR hardware in serious games is that it restricts use only to players who have access to such (not yet widespread) hardware. While a desktop version of the game might be inferior to the immersive one for the reasons summarized above, it would nonetheless have the advantage of being accessible to a much larger user population. To maximize the reach of our project, we are thus developing in parallel a desktop version of our game. While the narrative and graphics do not need changes for the desktop version, the user interface has to be redesigned to be usable in a desktop context. In particular, the desktop version of our serious game aims at supporting a point-and-click interaction that requires only a common desktop computer with mouse to play, and can be easily learned. The two versions of the game will co-exist and users will be able to download the immersive or the desktop one based on the hardware they have access to. We plan to carry out a study to analyze the possible differences in terms of engagement, learning and retention between the desktop and immersive versions of the game, but taking into account that they rely on different user interfaces and that factor could play a role too.

7 Conclusions

In this paper, we addressed three main research topics: (i) the proposal of an immersive VR approach that exploits some game design techniques to address safety education of the general public, using aviation as a relevant case study, (ii) the comparison of the immersive VR approach with a traditional safety education approach (safety card) in terms of learning, including an assessment of knowledge retention over time, (iii) the comparison of the immersive VR approach with the traditional method in terms of engagement and emotional arousal, which has been shown to be an important facilitator of memory retention (although in studies which did not include VR as ours did).

The paper obtained results for each of the three topics: (i) to the best of our knowledge, we proposed the first immersive serious game for aviation safety education of the general public, (ii) the experimental evaluation showed that, unlike the safety card, the immersive serious game produces in users a knowledge gain that is maintained after one week (people who used the card suffered instead a statistically significant loss of the acquired knowledge after one week), (iii) the immersive game was able to produce more engagement, negative emotion (fear) and physiological arousal than the safety card, a factor that can contribute to explain its positive impact on knowledge retention.

The immersive serious game approach we presented is not limited to aviation and could be easily adapted to other emergency preparedness domains. For example, we are working at applying it to civil defense, building game levels in which the player has to survive terror attacks to public places.

In addition to the virtual ditching scenario described in this paper, our serious game will feature multiple levels, aiming at motivating users to try more than one virtual aircraft emergency. The new levels we are building concern different types of survivable accidents (e.g., runway overrun and underrun, collision with other aircraft on the ground, crash landing in a field,…), specific threats (e.g., in-flight decompression, on-board fire, plane break-up during emergency landing, evacuation in night and in smoke conditions,…), and aircrafts (e.g., we are currently completing a detailed virtual reconstruction of a Boeing 777 twin-aisle, wide body aircraft [59]).

Once the effectiveness of all levels will be tested on users, we plan to make the serious game publicly available for PC and Mac platforms and track players' progress over time to assess longer-term knowledge retention and engagement. To increase the number of players who could receive immersive aviation safety education, we will also extend the system to support new consumer VR devices meant for home use, in addition to the Sony HMZ series. In particular, we are now considering the Oculus Rift as a low-cost solution that could possibly allow a larger population of users to start training with immersive serious games.

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References

[1] J. C. Silverstein, F. Dech, M. Edison, P. Jurek, W. S. Helton, and N. J. Espat, "Virtual reality: Immersive hepatic surgery educational environment," *Surgery*, vol. 132, no. 2, pp. 274–277, Aug. 2002.

[2] I. Kruglikova, T. P. Grantcharov, A. M. Drewes, and P. Funch-Jensen, "The impact of constructive feedback on training in gastrointestinal endoscopy using high-fidelity virtual-reality simulation: a randomised controlled trial," *Gut*, vol. 59, no. 2, pp. 181–185, Oct. 2009.

[3] M. Cha, S. Han, J. Lee, and B. Choi, "A virtual reality based fire training simulator integrated with fire dynamics data," *Fire Saf. J.*, vol. 50, pp. 12–24, May 2012.

[4] P. Backlund, H. Engström, C. Hammar, M. Johannesson, and M. Lebram, "Sidh - a Game Based Firefighter Training Simulation," in *11th International Conference Information Visualization - IV '07*, 2007, pp. 899–907.

[5] R. Hill, J. Morie, J. Rickel, M. Thiébaux, L. Tuch, R. Whitney, J. Douglas, W. Swartout, J. Gratch, W. L. Johnson, C. Kyriakakis, C. LaBore, R. Lindheim, S. Marsella, D. Miraglia, and B. Moore, "Toward the Holodeck: Integrating Graphics, Sound, Character and Story," in *Proceedings of the fifth international conference on Autonomous agents - AGENTS '01*, 2001, pp. 409–416.

[6] C. Cruz-Neira, D. Reiners, J. P. Springer, C. Neumann, C. N. S. Odom, and K. Kehring, "An Integrated Immersive Simulator for the Dismounted Soldier," in *The Interservice/Industry Training, Simulation & Education Conference (I/ITSEC)*, 2011.

[7] C. Girard, J. Ecalle, and A. Magnan, "Serious games as new educational tools: how effective are they? A meta-analysis of recent studies," *J. Comput. Assist. Learn.*, vol. 29, no. 3, pp. 207–219, Jun. 2013.

[8] R. G. W. Cherry, "A Study Analyzing the Trends in Accidents and Fatalities in Large Transport Airplanes," Technical Report DOT/FAA/TC-13/46, Washington, DC, USA, 2013.

[9] C. L. Corbett, G. A. McLean, and D. K. Cosper, "Effective Presentation Media for Passenger Safety I: Comprehension of Briefing Card Pictorials and Pictograms," Technical Report DOT/FAA/AM-08/20, Washington, DC, USA, 2008.

[10] D. Cosper and G. McLean, "Availability of passenger safety information for improved survival in aircraft accidents," Technical Report DOT/FAA/AM-04/19, Washington, DC, USA, 2004.

[11] D. C. Schwebel, J. Gaines, and J. Severson, "Validation of virtual reality as a tool to understand and prevent child pedestrian injury," *Accid. Anal. Prev.*, vol. 40, no. 4, pp. 1394–1400, Jul. 2008.

[12] A. C. A. Mól, C. A. F. Jorge, and P. M. Couto, "Using a Game Engine for VR Simulations in Evacuation Planning," *IEEE Comput. Graph. Appl.*, vol. 28, no. 3, pp. 6–12, May 2008.

[13] P. Backlund, H. Engström, M. Johannesson, and M. Lebram, "Games and Traffic Safety - an Experimental Study in a Game-Based Simulation Environment," in *11th International Conference Information Visualization - IV '07*, 2007, pp. 908–916.

[14] V. A. M. Jorge, W. J. Sarmiento, A. Maciel, L. Nedel, C. A. Collazos, F. Faria, and J. Oliveira, "Interacting with danger in an immersive environment: issues on cognitive load and risk perception," in *Proceedings of the 19th ACM Symposium on Virtual Reality Software and Technology - VRST '13*, 2013, pp. 83–92.

[15] Capcom co. ltd., "Resident Evil," 2014. [Online]. Available: http://www.residentevil.com/. [Accessed: 11-Sep-2014].

[16] Red Barrels inc., "Outlast," 2014. [Online]. Available: http://www.redbarrelsgames.com/. [Accessed: 11-Sep-2014].

[17] Activision Publishing Inc., "Call of Duty," 2014. [Online]. Available: http://www.callofduty.com/. [Accessed: 11-Sep-2014].

[18] Electronic Arts Inc., "Battlefield," 2014. [Online]. Available: http://www.battlefield.com/. [Accessed: 11-Sep-2014].

[19] Naughty Dog Inc., "Uncharted," 2014. [Online]. Available: http://naughtydog.com/games/uncharted/. [Accessed: 11-Sep-2014].

[20] Insomniac Games Inc., "Ratchet&Clank," 2014. [Online]. Available: http://www.insomniacgames.com/games/ratchet-clank-ps4/. [Accessed: 11-Sep-2014].

[21] E. D. van der Spek, H. van Oostendorp, and J.-J. Ch. Meyer, "Introducing surprising events can stimulate deep learning in a serious game," *Br. J. Educ. Technol.*, vol. 44, no. 1, pp. 156–169, Jan. 2013.

[22] T. Sharot, M. R. Delgado, and E. a Phelps, "How emotion enhances the feeling of remembering," *Nat. Neurosci.*, vol. 7, no. 12, pp. 1376–1380, Dec. 2004.

[23] K. S. LaBar and R. Cabeza, "Cognitive neuroscience of emotional memory," *Nat. Rev. Neurosci.*, vol. 7, no. 1, pp. 54–64, Jan. 2006.

[24] J. L. McGaugh, "Memory--a Century of Consolidation," *Science*, vol. 287, no. 5451, pp. 248–251, Jan. 2000.

[25] K. A. Nielson and T. J. Arentsen, "Memory modulation in the classroom: selective enhancement of college examination performance by arousal induced after lecture," *Neurobiol. Learn. Mem.*, vol. 98, no. 1, pp. 12–16, Jul. 2012.

[26] E. A. Kensinger, "Remembering the Details: Effects of Emotion," *Emot. Rev.*, vol. 1, no. 2, pp. 99–113, Jan. 2009.

[27] B. Finn and H. L. Roediger, "Enhancing retention through reconsolidation: negative emotional arousal following retrieval enhances later recall," *Psychol. Sci.*, vol. 22, no. 6, pp. 781–786, Jun. 2011.

[28] E. A. Kensinger, R. J. Garoff-Eaton, and D. L. Schacter, "Memory for specific visual details can be enhanced by negative arousing content," *J. Mem. Lang.*, vol. 54, no. 1, pp. 99–112, Jan. 2006.

[29] E. A. Kensinger and D. L. Schacter, "Memory and Emotion," in *Handbook of Emotions*, 3rd ed., M. Lewis, J. M. Haviland-Jones, and L. Feldman Barrett, Eds. New York, NY, USA: Guilford Press, 2008, pp. 601–617.

[30] Z. Merchant, E. T. Goetz, L. Cifuentes, W. Keeney-Kennicutt, and T. J. Davis, "Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis," *Comput. Educ.*, vol. 70, pp. 29–40, Jan. 2014.

[31] C. D. Coles, D. C. Strickland, L. Padgett, and L. Bellmoff, "Games that 'work': using computer games to teach alcohol-affected children about fire and street safety," *Res. Dev. Disabil.*, vol. 28, no. 5, pp. 518–530, 2007.

[32] L. Cahill, B. Prins, M. Weber, and J. L. McGaugh, "β-adrenergic activation and memory for emotional events," *Nature*, vol. 371, no. 6499, pp. 702–704, Oct. 1994.

[33] Airbus, "A320 Aircraft Characteristics Airport and Maintenance Planning", Technical Manual, 2014.

[34] National Transportation Safety Board, "Loss of Thrust in Both Engines After Encountering a Flock of Birds and Subsequent Ditching on the Hudson River, US Airways Flight 1549, Airbus A320-214, N106US, Weehawken, New Jersey, January 15, 2009," Accident Report NTSB/AAR-10 /03, Washington, DC, USA, 2010.

[35] QuanticDream, "Heavy Rain," 2010. [Online]. Available: http://www.quanticdream.com/en/game/heavy-rain. [Accessed: 11-Sep-2014].

[36] T. Litwiller and J. J. LaViola, "Evaluating the benefits of 3D stereo in modern video games," in *Proceedings of the 2011 annual conference on Human factors in computing systems - CHI '11*, 2011, pp. 2345–2354.

[37] K. W. Arthur, K. S. Booth, and C. Ware, "Evaluating 3D task performance for fish tank virtual worlds," *ACM Trans. Inf. Syst.*, vol. 11, no. 3, pp. 239–265, Jul. 1993.

[38] C. Dede, M. C. Salzman, R. B. Loftin, and D. Sprague, "Multisensory immersion as a modeling environment for learning complex scientific concepts," in *Computer modeling and simulation in science education*, W. Feurzeig and N. Roberts, Eds. New York, NY, USA: Springer-Verlag, 1999, pp. 282–319.

[39] W. Winn, M. Windschitl, R. Fruland, and Y. Lee, "When does immersion in a virtual environment help students construct understanding?," in *Proceedings of the international conference of the learning societies*, 2002, pp. 497–503.

[40] D. A. Bowman, L. F. Hodges, D. Allison, and J. Wineman, "The Educational Value of an Information-Rich Virtual Environment," *Presence Teleoperators Virtual Environ.*, vol. 8, no. 3, pp. 317–331, Jun. 1999.

[41] D. R. Montello, D. Waller, M. Hegarty, and A. E. Richardson, "Spatial Memory of Real Environments, Virtual Environments, and Maps," in *Human Spatial Memory*, G. L. Allen, Ed. Mahwah, NJ, USA: Lawrence Erlbaum Associates, 2004, pp. 251–286.

[42] H. Muir and L. Thomas, "Passenger education: past and future," in *Proceedings of the 4th Triennial International Aircraft Fire and Cabin Safety Research Conference*, 2004.

[43] L. J. Van Gerwen, P. Spinhoven, R. Van Dyck, and R. F. W. Diekstra, "Construction and psychometric characteristics of two self-report questionnaires for the assessment of fear of flying," *Psychol. Assess.*, vol. 11, no. 2, pp. 146–158, 1999.

[44] A. Nousi, L. van Gerwen, and P. Spinhoven, "The Flight Anxiety Situations Questionnaire and the Flight Anxiety Modality Questionnaire: norms for people with fear of flying," *Travel Med. Infect. Dis*., vol. 6, no. 5, pp. 305–310, Sep. 2008.

[45] C. P. McLean and E. R. Anderson, "Brave men and timid women? A review of the gender differences in fear and anxiety," *Clin. Psychol. Rev.*, vol. 29, no. 6, pp. 496–505, Aug. 2009.

[46] J. R. Ordoñana, F. González-Javier, L. Espín-López, and J. Gómez-Amor, "Self-Report and Psychophysiological Responses to Fear Appeals," *Hum. Commun. Res.*, vol. 35, no. 2, pp. 195–220, Apr. 2009.

[47] M. Benedek and C. Kaernbach, "Decomposition of skin conductance data by means of nonnegative deconvolution," *Psychophysiology*, vol. 47, no. 4, pp. 647–658, Jul. 2010.

[48] L. Chittaro, "Anxiety Induction in Virtual Environments: An Experimental Comparison of Three General Techniques," *Interact. Comput.*, vol. 26, no. 6, pp. 528–539, 2014.

[49] H. A. Lister, C. D. Piercey, and C. Joordens, "The effectiveness of 3D video virtual reality for the treatment of fear of public speaking," *J. CyberTherapy Rehabil.*, vol. 3, no. 4, pp. 375–381, 2010.

[50] A. Mühlberger, M. Sperber, M. J. Wieser, and P. Pauli, "A virtual reality behavior avoidance test (VR-BAT) for the assessment of spider phobia," *J. CyberTherapy Rehabil.*, vol. 1, no. 2, pp. 147–158, 2008.

[51] C. Tröger, H. Ewald, E. Glotzbach, P. Pauli, and A. Mühlberger, "Does pre-exposure inhibit fear context conditioning? A Virtual Reality Study," *J. Neural Transm.*, vol. 119, no. 6, pp. 709–719, Jun. 2012.

[52] J. L. Andreassi, *Psychophysiology: Human Behavior and Physiological Response*, 5th ed., Mahwah, NJ, USA: Lawrence Erlbaum Associates, 2007.

[53] B. H. Cohen, *Explaining Psychological Statistics*, 2nd ed. Hoboken, NJ, USA: Wiley, 2001.

[54] K. Meyerbröker and P. M. G. Emmelkamp, "Virtual reality exposure therapy in anxiety disorders: a systematic review of process-and-outcome studies," *Depress. Anxiety*, vol. 27, no. 10, pp. 933–944, Oct. 2010.

[55] T. D. Parsons and A. A. Rizzo, "Affective outcomes of virtual reality exposure therapy for anxiety and specific phobias: a meta-analysis," *J. Behav. Ther. Exp. Psychiatr.*, vol. 39, pp. 250–261, 2008.

[56] N. Ahmann, "Combining Stress Inoculation Training with Medical Training for Combat Medics," *J. CyberTherapy Rehabil.*, vol. 4, no. 2, pp. 12–13, 2011.

[57] B. J. Fogg, *Persuasive Technology: Using Computers to Change What We Think and Do*, San Francisco, CA, USA: Morgan Kaufmann, 2003.

[58] V. Narayanasamy, K. W. Wong, C. C. Fung, and S. Rai, "Distinguishing games and simulation games from simulators," *Comput. Entertain.*, vol. 4, no. 2, Article 9, Apr. 2006.

[59] Boeing, "Boeing 777," 2014. [Online]. Available: http://www.boeing.com/boeing/commercial/777family/index.page? [Accessed: 11-Sep-2014].