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Anxiety Induction in Virtual Environments: an experimental comparison of three general techniques

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Abstract

Anxiety induction and elicitation of associated physiological arousal with Virtual Environments (VEs) is important in diverse domains. This paper evaluates three general anxiety induction techniques. The first augments the VE with a health bar that is often displayed in video games to indicate when the user's avatar gets hurt. The second augments the VE with aversive audio-visual stimuli which are employed in first-person shooter games when the user's avatar gets hurt and include preset heartbeat sound. The third introduces in the previous technique a biofeedback mechanism to control heartbeat sound. The results we obtained on a VE that reproduces a fire evacuation indicate that the third technique produces much higher physiological arousal than the other two, and measures of users' state anxiety are consistent with physiological results. We discuss possible reasons that could explain why the exploitation of auditory heartbeat biofeedback contributes to make the third technique more effective, by linking our study to research and theories of affect and emotions.

Keywords: virtual environments, anxiety induction, biofeedback, heartbeat perception, affect

Research highlights

- We evaluate three general techniques for anxiety induction in virtual environments
- Two are used in video games, but lack a formal anxiety induction evaluation in the literature
- The third introduces a novel idea: using biofeedback in creating an illusory heartbeat change
- Our results indicate that the third technique is the most effective for anxiety induction
- We discuss the possible role of heartbeat biofeedback from a multidisciplinary perspective

1. Introduction

Anxiety induction and elicitation of associated physiological arousal with Virtual Environments (VEs) is important in diverse domains, e.g. stress inoculation training in medical responders and soldiers (Ahmann, 2011), treatment of stress-related disorders (Baños et al., 2011), phobia therapy (Lister, 2010) and assessment (Mühlberger et al., 2008), persuasive technology (Chittaro and Zangrando, 2010), psychology (Tarr and Warren, 2002). Explorations of which techniques are effective to induce anxiety in VEs and their relative strength are thus needed.

This paper evaluates three general techniques. The first two are routinely used in video games, but a formal anxiety induction evaluation is not available for them in the literature. The first technique is a bar that indicates the health of the user's avatar and decreases when it gets hurt in the VE. The second technique is a combination of aversive audio-visual stimuli which First-Person Shooter (FPS) games often employ when the user's avatar gets hurt. It includes heartbeat sound at a preset frequency that is increased to simulate a physiological change. The third technique introduces a novel idea: a biofeedback mechanism that produces an auditory perception of the user's own heartbeat and falsely increases its frequency when the VE has to induce anxiety. The second and the third technique use the same audio-visual stimuli and differ only in the way they control heartbeat sound (preset frequency vs. biofeedback mechanism).

While biofeedback-enhanced VEs are often used to decrease stress and anxiety, e.g. (Gorini et al., 2010; Repetto et al., 2013), our work aims at exploiting biofeedback for the opposite purpose, i.e. to increase anxiety and physiological arousal. The idea was inspired by the fact that hearing our own heartbeat change and become abnormal is an anxiety-inducing cue. For example, studies of anxiety-sensitive individuals (Pollock et al., 2006) have shown that, among the features of a panic attack, cardiac symptoms are rated as the most anxiety-provoking, and just hearing digitized files of abnormal heartbeat with a pair of headphones can be a relevant cue.

The paper is organized as follows. Section 2 discusses anxiety induction in VEs, outlining its importance for different applications and motivating our research, also considering studies of false heart rate feedback and theories of emotions. In Section 3, we illustrate in detail the three anxiety induction techniques and the experimental method followed to evaluate them. Section 4 presents the results of the experiment, while Section 5 discusses findings and limitations of the study. Section 6 contains conclusions and outlines future work.

2. Related Work and Motivations

In this section, we first motivate the need for anxiety induction in a wide range of applications (Sections 2.1 and 2.2). Then, we look more closely at different kinds of studies which employed false heart rate feedback to influence participants (Section 2.3) and highlight relations between our research and the related work (Section 2.4).

2.1 Psychology

Virtual Reality Exposure Therapy (VRET) is a treatment for anxiety disorders that exposes users to anxiety-inducing stimuli in VEs, aiming at extinction of anxious responses through prolonged VE use. VRET studies have focused on treating phobias and Post Traumatic Stress

Disorder, see (Krjin et al., 2004; Meyerbroker and Emmelkamp, 2010) for surveys. Two independent meta-analyses revealed that VRET has good potential in treating several specific phobias (Powers and Emmelkamp, 2008; Parsons and Rizzo, 2008). However, to be effective for VRET, the employed VEs must be able to elicit anxiety otherwise extinction will not occur (Krijn et al., 2004).

VEs can be also used for prevention and training purposes: in *Stress Inoculation Training* (SIT), they reproduce anxiety-inducing stressors that users are likely to encounter in the real world. SIT aims at helping people to develop better coping strategies and to learn to control emotional reactions when facing those stressors in their life. Ahmann (2011) illustrates how VEs are used for SIT interventions that involve soldiers and medical responders. SIT interventions in predeployment training (Hourani et al., 2011) can improve effectiveness in the field as well as help preventing the potentially harmful effects of exposure to traumatic events (Wiederhold and Wiederhold, 2008).

More generally, several psychology and neuroscience experiments need to induce anxiety in participants to study a wide range of theoretical topics, e.g., attention, learning and memory, executive functions, emotions, personality and individual differences, etc. They resort to various traditional methods for anxiety induction that include: cognitive tasks, e.g., carrying out difficult mental activities possibly under strict time constraints; visual and auditory stimuli, e.g., looking at disturbing pictures and film clips or being exposed to bursts of intense noise; particular social contexts, e.g., assigning participants a public speaking task or unknowingly involving them in socially stressful situations with the help of experimenter's confederates; administration of chemical substances, e.g., controlled inhalation of CO_2 or injection of pharmacological anxiogenics such as cholecystokinin tetrapeptide; self-induction, e.g., voluntary hyperventilation; pain, e.g., administration of electrical shocks. In this context, VEs are increasingly used as a novel anxiety-inducing tool because they can be more practical, more controllable and easier to manage than most of the above mentioned methods. In addition, VEs can involve participants in interactive situations that are similar to real-world experiences and thus less artificial than the above mentioned methods, increasing ecological validity (Tarr and Warren, 2002). VEs were shown to be effective in inducing states of anxiety in combination with traditional methods, e.g. electrical shockers (Baas et al., 2004; Truger et al., 2012), or more simply used alone, e.g. (Mühlberger et al., 2008; Freire et al., 2010; Baños et al., 2011).

2.2 Persuasive technology

Gass and Seiter (2010) underline that employing interactive technologies such as VEs and video games in persuasive interventions could be an appropriate channel to reach to the younger generations which have grown cynical of traditional media such as television and print ads. Other traditional scholars of persuasion such as Guadagno and Cialdini (2005) have encouraged researchers to specifically explore VEs as a persuasive channel.

A simulation can persuade people to change their attitudes or behaviors by enabling them to observe immediately the link between cause and effect (Fogg, 2003). VEs can vividly simulate the consequences of events and actions on users, and are increasingly employed for persuasion in domains that involve risk such as: health, e.g., encouraging people to exercise (Fox and Bailenson, 2009); safety, e.g., perception of fire risks (Chittaro and Zangrando, 2010); sustainability, e.g., attitudes towards climate change (Meijnders et al., 2006). These persuasive applications provide users with *virtual experiences of risk* such as floods (Zaalberg and Midden, 2010), fires (Chittaro and Zangrando, 2010), aircraft accidents (Chittaro, 2012) or weight gain (Fox and Bailenson, 2009).

Two major persuasive strategies exploited in virtual experiences of risk rely on anxiety-inducing stimuli as an essential component of the intervention. The simpler strategy is *operant conditioning*: user's responses that the application wants to encourage are reinforced through positive feedback, while those that need to be discouraged are punished with aversive feedback. Anxiety-inducing stimuli are used in highlighting the link between wrong user's behaviors (e.g., moving in smoke-filled corridors in a fire evacuation, eating unhealthy food or living a sedentary life) and their consequences (e.g., representing the pain and damage caused by smoke inhalation, changing the shape of the user's avatar to make it fat).

The second, more complex, persuasive strategy that emphasizes the negative consequences of specific behaviors is traditionally referred to as *fear appeal* (Witte and

Allen, 2000; Ruiter et al., 2001). From a terminological point of view, it must be noted that fear and anxiety are largely overlapping constructs, with subtle differences between them. While fear is an intense urge to defend oneself from an aversive stimulus, primarily by escape and avoidance, anxiety is an emotion that can persist well beyond the exposure to the stimulus, manifesting itself as a state of undirected arousal, more difficult to cope with by active defensive maneuvers (Öhman, 2008). Roger's protection motivation theory (PMT) (Rogers, 1983; Floyd et al., 2000) and Witte's Extended Parallel Process Model (EPPM) (Witte, 1992; Witte and Allen, 2000) are currently the two leading theoretical models of fear appeals. Both PMT and EPPM point out that effectively scaring and making people anxious about a risk is the first in a series of necessary steps that build a persuasive fear appeal. In particular, if fear and anxiety are not induced, the individual will not be motivated to consider how to cope with a risk in later steps of the model such as considering if there is an effective action that can avert the risk and evaluating if (s)he is capable of taking that action.

Finally, the need for effective anxiety induction techniques in virtual experiences of risk is also motivated by several field and experimental studies which showed that negative emotions heighten the perception of risk (Slovic, 2000). Perception of risk as feelings (instead of rational analysis) is so common in the way individuals form their attitudes that the term "affect heuristic" was coined to describe these instinctive and intuitive reactions (Slovic and Peters, 2006). Anxiety induction in VEs could thus be particularly useful when the virtual experience aims at changing perception of risks which are underestimated by people.

2.3 Studies of false heart rate feedback

Our emotions and decisions are influenced by the perception of our own bodily feelings. A seminal study that focused on auditory heart rate perception was carried out by Valins (1966). Participants were told that the "beep" sounds played by a machine indicated their heart rate, but the beeps were actually played at preset rates. Male participants looked at pictures of female seminude models while hearing the beeps, and the study found that pictures accompanied by a normal heart rate received lower ratings than the other pictures. This suggested that leading individuals to believe that their current heart rate is not normal has an effect on how they perceive the whole situation they are exposed to.

Several subsequent studies of false heart rate feedback involved also female participants and followed Valins' picture-rating paradigm, see (Misovich and Charis, 1974; Woll and McFall, 1979; Crucian et al., 2000; Barefoot, 2005), using pictures of opposite sex models as well as other kinds of pictures. For example, when looking at pictures of accident victims, false heart rate feedback was able to induce participants to rate the pictures as more repulsive (Misovich and Charis, 1974). Recent studies have begun to employ false heart rate feedback beyond the picture-rating paradigm. In particular, Gu et al. (2013) used false heart rate feedback to influence decisions in situations which require the participant to take moral choices, while Strain et al. (2013) used it to influence meta-cognitive judgment and performance in students faced with a challenging learning task. All the above mentioned studies concur that false heart rate feedback can influence participants' emotional state and decisions.

Theories of emotions provide possible explanations for the effects of false heart rate feedback. Both classic and modern theories posit that bodily states contribute to emotional experience. For the first historical theories of emotion proposed by James and Lange - see (Friedman, 2010) for a detailed account - bodily states were essential because emotions were seen as our perception of physiological reactions, and change in the heart rate is one of the possible reactions. Contemporary theories instead distinguish between two levels of emotional experience, introducing a level of (conscious or unconscious) cognitive appraisal of physiological changes (Russel, 2003; Wiens, 2005; Barrett et al., 2007). In other words, if a physiological change occurs, the affective state that a person experiences depends on an evaluation of the current situation that presumably caused that physiological change. The person's choice of an explanation will in large part determine the nature of the subsequent subjective and behavioral manifestations. In the above mentioned experiments, participants (consciously or unconsciously) interpret false heart rate feedback in the context of the other stimuli and information provided in association with it. When presented with seminude models pictures, abnormal heart rate is interpreted as an effect of attractiveness and leads participants to perceive the pictures as more attractive. Similarly, the interpretation process of abnormal heart rate leads participants to perceive accident victims' pictures as more repulsive.

Finally, it is worth noting that the link between self-perception of bodily states and emotion elicitation has recently received support from neuroscience studies which have identified similar patterns of brain activity for the two processes in some cortical regions, especially in the anterior insula (AI). For example, Zaki et al. (2012) conducted a within-groups experiment in which participants monitored their own heartbeat in one task, while in another task they watched affective video clips and rated their own emotional responses. The study showed that the two tasks engaged the same AI area, and activity in the area correlated with the intensity of emotional experience. This apparent convergence of self-perception and emotional processes in the AI has led also neuroscientists to reason that perceptions of bodily states - as supported by this region - are central to emotional experience (Craig, 2009; Singer et al., 2009; Zaki et al. 2012).

2.4 Relations with the present study

The previously described, diverse applications of VEs share a common need for anxiety induction. Theoretical studies in psychology need to induce different levels of anxiety to assess how the dependent variables of interest change as anxiety increases. VRET and SIT applications need to carry the user through a series of experiences characterized by different, increasing levels of anxiety. In persuasive VEs, the level of induced anxiety that makes a fear appeal effective varies with the considered risk. For example, a strong anxiety induction technique can be appropriate for a persuasive VE that concerns fire evacuation of public buildings, because people tend to downplay the severity of that risk and overestimate their ability to move in the dangerous environment (Proulx, 2003). On the contrary, the same technique can be counterproductive in a persuasive VE that teaches passengers proper behaviors in aircraft evacuations because people tend to be already anxious about aircraft emergencies and fearful of even normal flying conditions (Chittaro, 2012).

Explorations of which techniques are effective to induce anxiety in VEs and their relative strength are thus needed. While the simulation of specific anxiety-inducing events (e.g., a crawling spider, a fire in a building, a gun-toting man) is inevitably of interest only to a few applications, general techniques could be incorporated into any VE to augment its anxiety-inducing effects, and could thus be beneficial to all the previously mentioned applications.

In this paper, we evaluate three general techniques that indicate that the user's avatar is hurt by the situation experienced in the VE, regardless of which specific situation is represented. These techniques could be useful in many virtual experiences of risk, e.g., fires, accidents, explosions, hazardous materials, threat from animals or humans, hurtful objects and actions. Two of the studied techniques include heartbeat sound that increases in frequency to simulate a physiological change.

Our approach to providing false heart rate feedback differs from all the above mentioned studies in three important aspects. First, in all those studies, participants were verbally deceived by experimenters who told them that they were going to hear their own heartbeat, while we did not tell anything to deceive participants in our study. Second, we introduced a computer-controlled biofeedback technique based on heartbeat sound to create an illusion of heartbeat change, while all those studies relied only on preset sounds which were unrelated to the actual participant's heart rate. Third, we employed our technique for a different purpose (anxiety induction) in a different context (simulation of a fire evacuation) and with a different apparatus (immersive virtual reality).

3. Method

To compare the anxiety induction effectiveness of the three considered techniques, we carried out a between-groups study, as described in detail by this section.

3.1 Design

The VE employed in the experiment reproduced the anxiety-inducing experience of being suddenly surrounded by smoke during a fire evacuation of a building. In all three experimental conditions, participants saw the same visual simulation of smoke filling the corridors of the building. The conditions differed in the anxiety-inducing stimuli added to that visual simulation.

In the *Health Bar* condition, a horizontal green bar (Figure 1) displayed the level of health of the user's avatar during the virtual experience. The bar progressively decreased in length when the participant was in the anxiety-inducing situation, indicating that the participant's avatar was getting hurt. More specifically, when the participant was not in the anxiety-inducing situation, the green bar was always completely filled. During the anxiety-inducing situation, the length of the bar decreased at a constant speed, becoming completely empty in 30 seconds.

<FIGURE 1 HERE>

The *FPS* condition exploited the aversive auditory and visual stimuli that First Person Shooter video games routinely employ to indicate that the user's avatar is getting hurt. To identify these stimuli, we examined some popular violent video games - such as Call of Duty 4 (Activision, 2012) and Mirror's Edge (Electronic Arts, 2012) - and reproduced the combination of stimuli they employ. More specifically, during the anxiety-inducing situation: (i) an heartbeat sound whose frequency progressively increased and a respiration sound whose frequency progressively increased were played, (ii) the visual field of view was reduced to simulate tunnel vision phenomena which occur in extreme stress conditions (Figure 2a), and (iii) a red aura flashed (Figure 2b) in synch with the heartbeat sound. The preset change in cardiac frequency started from a normal resting frequency for a healthy adult in a sitting position (60 BPM) and linearly increased to its triple (180 BPM) in 30 seconds.

<FIGURE 2 HERE>

The *bioFPS* condition was identical to the FPS condition except for the fact that heartbeat sound was controlled by the proposed biofeedback mechanism. We employed a pulsioxymeter on the participant's earlobe to detect cardiac frequency. When the participant was not in the anxiety-inducing situation in the VE, we played heartbeat sound at his/her actual frequency so that she got used to hear his/her own heartbeat and its actual changes while (s)he navigated the VE. When the participant was confronted with the anxiety-inducing situation, we changed the speed of the played heartbeat to create the illusion that his/her own heartbeat was becoming abnormal. Starting from the participant's actual frequency, the played heart rate was linearly increased until it tripled in 30 seconds. If the seated participant's actual frequency was greater or equal to 74, the final played frequency was kept realistic by not allowing it to exceed the physiological limit of 220 BPM, i.e., maximum heart rate for humans. When the anxiety-inducing situation ended, we reverted to playing the participant's actual heartbeat: frequency returned to the actual one in about 1 second.

We hypothesized that bioFPS induces higher levels of anxiety as well as associated physiological arousal in participants compared to Health Bar and FPS. In particular, we reasoned that Health Bar is essentially a bar chart that provides only factual feedback about the health status of the user's avatar, with no explicit visual or auditory emotional depiction of the negative effects of getting hurt. The other two conditions provided such depiction, and differed only in the way heartbeat sound was controlled. Studies about false heart rate feedback and emotions (as seen in Section 2.3) would have suggested that in our case false heart rate should contribute to increase anxiety. However, all those studies employed verbal deception to influence participants into associating preset heart rate to their own heart rate, while we did not. As a result, FPS did not employ any technique to influence participants into associating the sound they were hearing to their own heartbeat, while bioFPS created this association by using the biofeedback mechanism. Finally, there is ample evidence that cardiac awareness (i.e., a person's ability to perceive his/her own heartbeat) is in general associated with the intensity of the person's emotional experience, see (Herbert et al., 2010) for a review. This further motivated our hypothesis because the biofeedback mechanism increases cardiac awareness by playing user's actual heartbeat through the headphones and this should thus contribute to provoke a more intense emotional experience.

3.2 Materials

Figure 3 shows the equipment used by the VE in the experiment. Participants donned a stereoscopic head-mounted display (HMD) with 800*600 resolution, 31.2° field of view, 3DOF head tracker, audio headphones, and held a Nintendo Nunchuck joystick in their dominant hand. The joystick allowed them to move in the VE: the up and down commands on the joystick allowed participants to move respectively forward and backward, while the right and left commands were used to rotate respectively right or left. When participants approached a closed door, the words "open door" clearly appeared in the environment and participants could open it by pressing the trigger button on the joystick. A pulsioxymeter on the participant's earlobe allowed the biofeedback technique to detect heart rate.

<FIGURE 3 HERE>

The VE was implemented using C# and NeoAxis (2012), a game engine based on the Ogre rendering engine (2012). The sequence of events in the virtual experience was strictly controlled: predefined events occurred at preset times regardless of participants' movement speed or paths followed in the environment. In particular, the participant was surrounded by smoke at two different preset times during the experience.

3.3 Participants

Participants were recruited through personal contact and a campus mailing list for general announcements. A total of 108 participants (84 male, 24 female) was recruited and each of the three experimental groups included 28 male and 8 female participants. Participants were volunteers who received no compensation. Most of them were students enrolled in different programs (engineering, medicine, computer science, business administration, architecture). The mean age of participants was 24.1 (SD=3.2).

All participants were familiar with VEs or video games. We assessed individual differences with respect to FPS games (which use most of the studied aversive stimuli) by asking participants to rate their frequency of use of FPS games on a 7-point scale (1=never, 7=several hours a day) and liking of FPS games on another scale (1=not at all, 7=a lot). Means in the Health Bar, FPS, and bioFPS groups were respectively 2.44 (SD=1.21), 2.44 (SD=1.54), 2.53 (SD=1.23) for frequency of use, and 5.13 (SD=1.21), 5.09 (SD=1.07), 5.17 (SD=1.20) for liking of FPS games. These very small differences among the three groups are not statistically significant ($p>.8$ for frequency, $p>.9$ for liking) as confirmed by a Kruskal Wallis test.

3.4 Measures

3.4.1 Physiological arousal

To measure participants' level of physiological arousal elicited by the three conditions, we recorded electrodermal activity with a Thought Technology Procomp Infiniti system. In particular, we focused on skin conductance level (SCL), which is increasingly used in studies of stress and anxiety in VEs, e.g. (Lister et al., 2010; Mühlberger et al.; 2008; Valtchanov and Ellard, 2010). SCL is the more stable of the two components of the electrodermal signal and is typically used to measure the level of electrodermal activity during a given period of time (Andreassi, 2007).

Before the VE experience, we measured participants' baseline values, i.e., the signal values that can be observed when participants are in a resting state. When analyzing physiological data, the participant's baseline value has to be subtracted from the data recorded during the experimental condition, to separate the physiological responses to experimental stimuli from the intrinsic biological differences among participants (Andreassi, 2007).

3.4.2 Change in state anxiety

To measure participants' state anxiety, we used the State-Trait Anxiety Inventory Form Y (STAI) (Spielberger, 1983). The state anxiety part of the questionnaire comprises 20 items that ask how much participants agree with sentences about their current state (e.g., "I feel safe", "I feel relaxed", "I feel nervous", "I feel worried") on a 4-point Likert scale (1=Not At All, 2=Somewhat, 3=Moderately So, 4=Very Much So). Based on the answers, the STAI assigns a score from 20 to 80 to participant's state anxiety.

State anxiety measured before the VE experience was very similar in the three groups: means were equal to 33.8 (SD=6.35) for the Health Bar group, 34.5 (SD=6.17) for FPS, and 33.2 (SD=6.04) for bioFPS. These small initial differences among groups are not statistically significant as confirmed by a 1-way ANOVA ($p>.6$).

As a measure of change in anxiety, we took the difference between state anxiety scores measured after and before the VE experience.

3.5 Procedure

Participants were clearly informed that they could refrain from continuing the experiment at any time without providing a reason to the experimenter. This is particularly important in experiments that can induce anxiety, because there is a chance that participants might find the experience too stressful and change their mind about participation.

First, participants were seated and filled the initial questionnaires and the STAI. Then, we applied skin conductance electrodes to two fingers of the non-dominant hand, and the pulsioxymeter to the earlobe of participants. Although the pulsioxymeter was needed only for the bioFPS group, we applied it to all participants to avoid introducing a confounding factor. Participants were not informed of the actual purpose of the pulsioxymeter. In all three groups, they were told that the general goal of the experiment was to evaluate the VE by collecting questionnaire as well as physiological data with the sensors on the hand and on the earlobe.

Once the sensors were in place, participants were asked to relax for three minutes to record their physiological baseline values. During baseline recording, a video with relaxing images and music was shown in a dim light. Participants could close their eyes and only listen to the music if they preferred.

After baseline recording, participants donned the HMD and were immersed in a training VE (a small building) to familiarize with controls. The experimenter told them which training goal to achieve in a fixed sequence: move around using the joystick, look around by moving the head, follow a short path indicated by arrows, open some specific doors, go look at some specific objects closely, look at the emergency exit signs in a room and a corridor. The familiarization phase lasted about 2 minutes, then we switched to the experimental VE, placing participants into a room of a large virtual building.

We waited a few seconds to allow participants to adapt to the change in environment and then we instructed them to perform a sign-following task. This initial waiting and task description time lasted for a total of 15 seconds. To describe the task, we simply told participants to reach the exit of the building by following the signs placed on walls. The VE reproduced accurately the familiar signs which are legally mandatory for public buildings in the participants' country. When speaking to participants, we were careful not to refer to time, speed or deadlines, because - as mentioned in Section 2.1 - time pressure is a typical method for inducing stress and anxiety, while our experiment focused on assessing the anxiety-inducing capabilities of the considered VE stimuli. Along the way in the VE, participants were subjected to two smoke situations, whose timing and duration was the same for all groups. The three conditions differed in the additional stimuli provided during the two smoke situations as described in Section 3.1. The first smoke situation occurred after 1 minute from the start of the sign-following task: the participant was surrounded by smoke that persisted around him/her for 30 seconds, regardless of his/her movements. After the first situation, smoke disappeared and the environment was clear for 1 minute. Then, the second smoke situation started and lasted for 30 seconds. Unbeknown to participants, the large size of the building made it impossible to reach the exit within the total time length of the experience. At the end of the second smoke situation, the environment faded away, we invited the participant to remove the pulsioxymeter and HMD, and administered the STAI again.

4. Results

4.1 Physiological arousal

After baseline subtraction, we identified SCL extreme outliers, i.e. values which are smaller than Q1–3*IQR or greater than Q3+3*IQR, where IQR is the interquartile range, Q1 the first quartile, and Q3 the third quartile. Extreme outliers were removed at the group level: there was 1 extreme outlier in the Health Bar condition, 2 in FPS, and 1 in bioFPS. Then, we ran a between-subjects ANOVA with SCL as dependent variable that revealed a significant effect, $F(2,101)=7.85$, $p<.01$, $\eta^2=.14$. Bonferroni post-hoc analysis showed that the difference between bioFPS and Health Bar ($p<.01$) and the difference between bioFPS and FPS ($p<.05$) were significant, with bioFPS eliciting much more physiological arousal than the other two conditions. The difference between Health Bar and FPS was instead small and not significant. The average increase in SCL (Figure 4) with respect to baseline values was .01 μS (SD=.31) for Health Bar, .07 μS (SD=.19) for FPS, and .30 μS (SD=.46) for bioFPS.

<FIGURE 4 HERE>

4.2 Change in State Anxiety

We ran a between-subjects ANOVA with change in state anxiety as dependent variable. The effect was significant, $F(2,105)=4.06$, $p<.05$, $\eta^2=.07$, with an average increase in anxiety (Figure 4) equal to 1.5 (SD=6.3) for Health Bar, 2.2 (SD=7.4) for FPS, and 5.5 (SD=5.3) for bioFPS, i.e. a 4.5%, 6.3%, and 16.6% anxiety increase in the respective three groups. Post-hoc analysis with Bonferroni test showed that the difference between bioFPS and Health Bar was significant ($p<.05$).

5. Discussion

The results of the experiment confirm our hypothesis. While the difference between Health Bar and FPS was small and not significant, bioFPS elicited much more physiological arousal than Health Bar as well as FPS, and state anxiety scores measured with the STAI were consistent with physiological arousal results. It is worth remembering that FPS and bioFPS differed only in the way heart rate feedback was controlled: it was preset in FPS, while it was related to the actual participant's heartbeat by the biofeedback mechanism in bioFPS.

Looking qualitatively at the SCL signals over time (see Figure 5), the average SCL value in the Health Bar condition remained low and close to zero during the entire virtual experience, regardless of the presence of smoke and the displayed changes in the bar, indicating that Health Bar was not able to elicit physiological arousal in users. Interestingly, the signal for FPS and bioFPS behaves similarly to Health Bar during the initial part of the experience (i.e., before the first smoke situation) but then it rises up over Health Bar for the rest of the experience, with bioFPS always higher than FPS.

<FIGURE 5 HERE>

In terms of appraisal theories of emotion (see Section 2.3), when participants evaluated the physiological change illusion created by the biofeedback technique, they referred to the associated anxiety-inducing virtual experience as a presumable cause. This could have lead them to perceive that experience as more arousing and anxiety-inducing. It is interesting to note that FPS, the condition which used preset heart rate, was instead not much effective. This could be due to the fact that, unlike all traditional studies of false heart rate feedback, we did not use verbal deception to influence participants into associating the played heart rate to their own heart rate. As a result, the association had to be created by other means. The FPS condition had no means to compensate for the lack of verbal deception. The bioFPS condition associated instead the played heart rate with participant's actual heart rate by using the biofeedback mechanism. This also suggests that biofeedback could be more generally explored as a way to eliminate the need for verbally deceiving users in false heart rate feedback studies.

A difference among the three conditions that should be noted concerns auditory stimuli and their known impact on physiological arousal. The Health Bar condition provided no auditory stimuli: the damage inflicted on the virtual user's body was accounted for through a factual bar chart. The other two conditions used instead aversive auditory stimuli, which are able by themselves to induce a physiological reaction (Bradley and Lang, 2000), and were based on cardiac and respiratory sounds indicating damage to the virtual user's body. These considerations would lead one to predict larger physiological arousal with FPS and bioFPS compared to Health Bar. As we have seen, the stimuli were actually not sufficient to elicit a significantly larger physiological reaction in FPS, while the addition of the biofeedback mechanism to the same stimuli proved able to potentiate response and reach significantly larger arousal compared to Health Bar as well as FPS. This reinforces the importance of appraisal theories of emotion in interpreting our results: FPS and bioFPS used the same sounds and visual effects, but the physiological change illusion created by bioFPS could have been appraised by participants as an effect on their real body of the anxiety-inducing experience depicted by the VE, which would explain the larger physiological arousal and state anxiety.

We could consider an alternative interpretation of our results that might confirm the importance of false heart rate feedback but downplay the role of the biofeedback mechanism. As we have seen, the physiological change played in the FPS condition was the same for all participants. In the bioFPS condition, it depended on the participant's actual physiological state and could be thus smaller as well as greater than the preset change of the FPS condition. More specifically, the increase in BPM in the FPS group was 120 for all participants, while the increase in BPM in the bioFPS group ranged from 110 to 146 BPM (M=130, SD=1.66). One could thus conjecture that some participants in the bioFPS group became more aroused and anxious just because the physiological change played to them was larger. However, this conjecture relies on the assumption that playing a larger physiological change should produce more arousal and state anxiety than a smaller one, i.e. the increase in BPM played in the bioFPS group should be positively correlated with the dependent variables. We thus checked with Pearson's test if such a correlation was present: the results for increase in BPM and SCL ($r(35)= -.22$, p=.21) as well as for increase in BPM and change in state anxiety ($r(36)=.15$, p=.37) do not support the conjecture.

Another possible alternative explanation that we might consider concerns distance traveled in the VE. As mentioned before, unbeknown to participants, the size of the virtual building made it impossible to reach the exit within the time length of the experience. We may thus argue that the more a participant traveled without seeing the exit of the building, the more anxious (s)he might have become. In this way, a possibly larger traveled distance in the bioFPS group could be an alternative explanation of the results obtained. We thus computed distance traveled from the logs of participants' positions in the VE to check for possible differences. The length of the path to the exit in the VE was equivalent to 300 meters in a real-world building, and the distance traveled by participants was very similar in the three groups: means were equal to 229.9 (SD=19.37) meters for the Health Bar group, 226.2 (SD=19.45) for FPS, and 228.9 (SD=22.24) for bioFPS. These small differences among groups are not statistically significant as confirmed by a 1-way ANOVA ($p>.7$) and distance traveled is not supported as an alternative explanation for the obtained results.

Recent research in virtual reality has focused on the relations between emotions and sense of presence, which can be defined as the "psychological state in which even though part or all of an individual's current experience is generated by and/or filtered through human-made technology, part or all of the individual's perception fails to accurately acknowledge the role of the technology in the experience" (International Society for Presence Research, 2000). Although we have not explicitly measured sense of presence in our experiment, the results we have obtained might have relations with this construct. In particular, Riva et al. (2007) showed that a bidirectional relation exists between sense of presence and anxiety in VEs: on one side, sense of presence increases in those VEs that are able to effectively elicit anxiety; on the other side, the level of anxiety is influenced by the level of presence. The mediating role that sense of presence plays between the virtual experience and the anxious emotional state induced by it suggests that the biofeedback-based condition in our experiment might have induced a greater sense of presence compared to the other conditions. This conjecture is explained in more detailed terms by a recently proposed general framework (Riva and Mantovani; 2012; Riva et al.; 2011; Villani et al., 2012) that describes presence as a metacognitive process that allows us to control our actions through the comparison between intentions and perceptions and explicitly deals with embodiment aspects. This framework is particularly relevant to our study for the following two reasons.

First, the three general techniques for anxiety induction we considered differ in the intensity with which they try to relate anxiety-inducing cues in the VE with the user's actual body. The Health Bar technique limits itself to provide a factual bar chart assessment of body health and thus provides no proprioceptive cues. The FPS technique includes visual (tunnel vision) and auditory (pre-recorded heartbeat and respiration sounds) cues to reproduce the proprioceptive experience of a suffering virtual body in the environment. The bioFPS technique aims at increasing the connection with the user's real body by building a link between cardiac auditory stimuli in the VE and the actual cardiac activity that participants feel in their real body.

Second, the three techniques give users a perceivable assessment tool for their intention to survive in the environment in order to reach the exit. In terms of Riva and Mantovani's general framework, participants in our experiments exerted a second-order mediated action on the VE. They indeed used a joystick (proximal tool) to move their avatar (distal tool in a virtual space) to reach a desired location, i.e. the exit in the virtual space (external virtual object). In this sense, the feedback about the body we provided in the three conditions is a tool that informs the user about the damage that his/her body is suffering in the virtual space and thus the likelihood of being unable to evacuate the building (reach the desired virtual object). As the framework points out, second-order mediated action is psychologically based on the integration of two different body models: a model based on proprioceptive data and centered on the real body; a model centered on the distal tool (visual data) which competes with the proprioceptive model. We can thus conjecture that our biofeedback-based condition (bioFPS) reduced this competition, making the two different peripersonal spaces closer by blurring the distinction which participants feel between their real body peripersonal space and the peripersonal space surrounding the distal tool in the VE.

A possible limitation of our study concerns the predominance of men in the sample. However, the possible consequences of this predominance on anxiety and arousal measures are known in the literature. There is indeed substantial evidence from several studies that women report greater anxiety than men, see (McLean and Anderson, 2009) for a comprehensive review of the literature. More generally, women tend to report higher intensities of emotional experience than men (Grossman and Wood, 1993; Hess et al., 2000) and show larger physiological affective reactions (Codispoti et al., 2008). The predominance of men in our sample might thus have attenuated the measures we obtained, and replicating the experiment with a gender-balanced sample is likely to produce larger values on the STAI scores as well as arousal measures.

6. Conclusions and Future Work

The experiment presented in this paper contrasted three general techniques for anxiety induction in VEs. Two of them were based on stimuli employed in video games, while the third introduced a novel way of exploiting biofeedback. The third technique produced much higher physiological arousal than the other two, and measures of users' state anxiety were consistent with physiological results.

Since it is based on auditory heartbeat perception, the proposed biofeedback mechanism can be generally incorporated into any existing VE without necessarily changing the graphics. In our case, the bioFPS condition of the experiment differed from the FPS condition only in the introduction of the auditory biofeedback technique, leaving unchanged all the graphic elements and the type of sounds played. Therefore, the idea can be of interest to any researcher and practitioner who needs to induce anxiety in a VE or to augment the anxiety-inducing techniques (s)he currently employs.

We are now continuing the exploration of the effects of the considered anxiety induction techniques with respect to additional variables (e.g., risk perception) as well as different VEs, such as a train station bombing experience, a medical triage experience, an earthquake experience. The study we described in this paper measured anxiety and arousal with a single questionnaire (STAI) and a single physiological measure (SCL). To obtain a more complete picture of users' emotional response, our new studies will employ a larger set of physiological recordings, which will include facial electromyography, electrocardiography and electroencephalography. Moreover, we will include additional questionnaires for affective state assessment such as the PANAS (Watson et al., 1988), and for measuring sense of presence such as the ITC-SOPI (Lessiter et al., 2001).

Finally, our future work will be also devoted to further the investigation of the techniques in the context of persuasive technology, focusing in particular on using virtual experiences of risk to foster awareness about personal fire safety and more generally emergency preparedness. While the findings of this paper contribute an effective anxiety-induction technique that can be used by the persuasive strategies we examined in Section 2.2, we will extend the investigation to additional variables proposed by the PTM and EPPM models. For example, susceptibility to risk could be manipulated by situating the virtual experience in contexts that belong to participants' daily life vs. contexts in which participants are very unlikely to find themselves in. For example, a fire emergency can be situated in environments such as a shopping mall or a home vs. environments such as an oil rig platform or an underground mine. To further link the EPPM and PTM with virtual experiences of risk, we also plan to study if and when increasing anxiety in the virtual experience could become detrimental to persuasion, e.g. resulting in user's defensive responses such as self-distancing denial and message derogation.

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(a)

(b)

Fig. 1. Examples of participant's view in the Health Bar condition. The green bar is respectively indicating that: (a) the user is fully healthy, (b) the user is getting hurt.

(a)
(b)


Fig. 2. Examples of participant's view in the FPS and bioFPS conditions: (a) tunnel vision phenomena, (b) red aura flash.

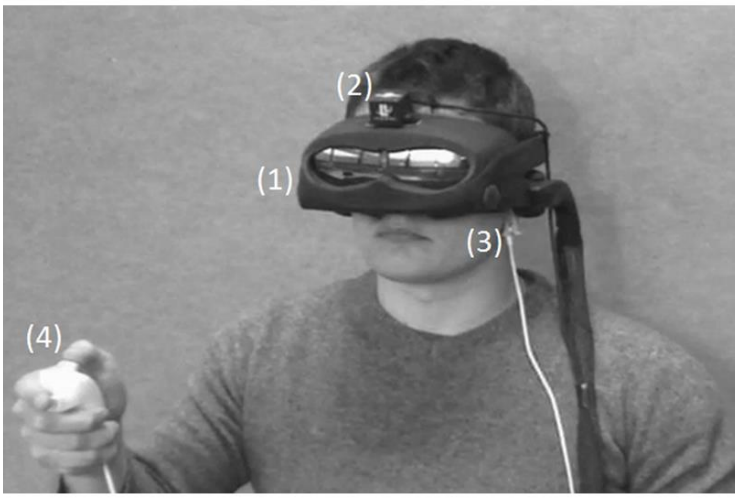

Fig. 3. Equipment used by the VE: 1) head-mounted display (HMD), 2) head tracker, 3) pulsioxymeter, 4) Nintendo Nunchuck joystick.

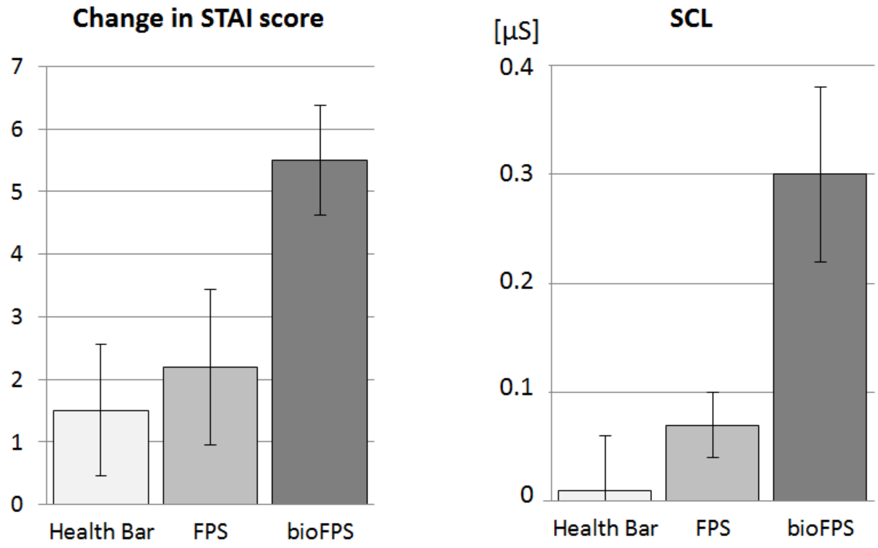

Fig. 4. Effect of anxiety-inducing technique on Change in State Anxiety and SCL. Capped vertical bars denote ±1 SE.

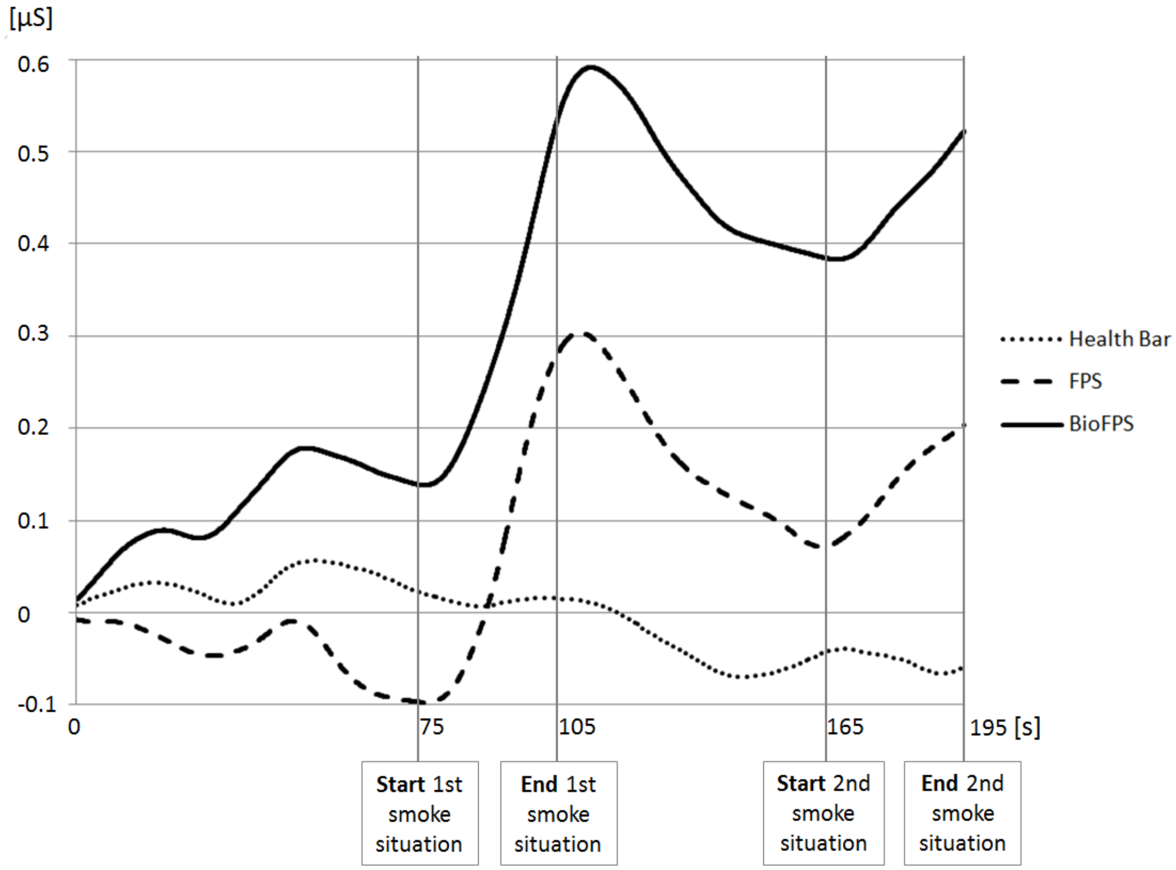

Fig. 5. Average SCL change with respect to participants' baseline value during the virtual experience.