Who Fears the Big Bad Climate Change? Analysis of Emotional Reactions to Global Warming in Virtual Reality

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Abstract. Climate change is one of the most challenging issues of our times, but it seems that humanity does not always realize the kind of consequences our current everyday habits will have on our planet. Virtual Reality is a powerful technology that can provide a wide range of immersive experiences, including representations of circumstances that can be far in space and in time. The current work presents a virtual reality futuristic depiction of the city of Torino, in Italy, that includes the scary representation of some of the effects of climate change on nature, people, and urban assets. We run a user study to measure the positive and negative emotions induced by these audio-visual effects, and found that the ones related to nature have the highest negative emotional impact.

Keywords: virtual reality · climate change · climate education · sustainable behavior · environmental awareness

1 Introduction

The global climate crisis has become one of the main challenges of the 21st century [9]. One of the most difficult aspects of dealing with global warming is getting people to understand the relevance of their personal actions on the environmental change, since the consequences of our everyday choices will be visible and tangible on this planet in a long-term, or at least non-immediate, perspective. According to a meta-analysis by van Valkengoed *et al.* [18], intense emotions were found to have an impact on the adoption of sustainable behaviors. In these terms, we questioned how visualizing a dystopian future could elicit an emotional impact, and therefore motivate participants towards a change.

Virtual Reality (VR) has frequently and effectively been used as an educational tool to change people's behavior on a variety of topics [10], including climate change awareness [2,12,15], since it increases motivation and involvement [1]. This technology also showed to be useful for making environmental concepts tangible and concrete, illustrating long-term and large-scale negative environmental consequences, or showing specific natural scenarios that may be economically, geographically, or safety-wise inaccessible [3].

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The European Commission developed the Consumption Footprint Platform [13], a Life Cycle Assessment (LCA)-based framework designed to monitor the overall environmental footprint of production and consumption within the European Union. The platform includes five areas of consumption: food, mobility, housing, household goods and appliances. The platform's latest assessment in 2021 reveals the environmental impact contribution of each area of consumption for an average EU citizen is: food accounts for 48.3%, mobility 14.9%, housing 19.5%, household goods 10.9%, and appliances 6.3% of the total environmental footprint.

To educate and promote pro-environmental behavior, we propose an interactive VR experience focused on people's everyday lives at home and in their neighbourhoods, based in the city centre of Torino, in Italy, where our laboratory is. An assessment of consumption in the city of Torino [5] revealed a different environmental impact distribution in the five areas of consumption: food accounted for 24.4%, mobility for 20%, housing for 28.3%, household goods for 18.4%, and appliances for 8.9% of the total consumption impact.

So, we developed a virtual reproduction of the city center of Torino, together with several visual effects (VFX) that suggest the worsening of environmental conditions. The project aims to increase participants' awareness of the impact of their daily actions have on climate change by inducing an emotional reaction. In this context, several works proposed the visualization of a future dystopian scenario to push emotional responses to the participants. In contrast, our work aims at quantifying those emotive reactions, focusing on which visual effects evoke both positive and negative emotions, which is a novel aspect to the authors' knowledge. So, we formulated the following research questions:

- **RQ1.** Can the exploration and visualization of a dystopian scenario have an emotional impact on participants?
- **RQ2.** To what extent can visual effects convey negative emotions?

Additionally, we provide an analysis of the quality of the VR experience, according to the opinion of the users, to assess the effectiveness of the application's design and development.

Fig. 1. Virtual reproduction of the skyline of Torino

2 Related Work

Virtual Reality proved to be an effective educational tool in different fields and contexts [10], leading to an increase in involvement and motivation in students [1]. In recent years, several projects have specifically focused on the promotion and teaching of pro-environmental attitudes and strategies through VR. However, the majority of these projects primarily focus on a single aspect of the climate emergency or rely on non-interactive experiences.

Through manipulation of temporal and spatial scales, VR allows to simulate future conditions that would otherwise be unobservable. In several works, the long-term environmental degradation processes are compressed into just a few minutes, increasing the environmental awareness of participants. Ferris *et al.* proposed Melbourne 2100 [4], a visit to a 3D reproduction of the city of Melbourne in 2100 flooded as a consequence of climate change. The experience increased the awareness of the users through an emotional impact. Similarly, Thoma *et al.* [16] proposed non-interactive visualization of the Aletsch glacier melting and investigated how visual realism of a virtual experience (in terms of texture resolution, the topography fidelity and color) affected climate change awareness and environmental attitudes. While the results of the experiment confirmed the overall effectiveness of VR interventions in conveying pro-environmental messages, no findings indicating a significant preference for realism has been found.

While the mentioned works are passive experiences, there are several examples of interactive serious games [20], enabling users to actively participate in the experience. Plechat *et al.* [11] developed a VR app for embracing pro-environmental dietary change by showing the effect of the participant's dietary footprint on nature, through the effect. In particular, users experienced in VR the environmental condition of a natural park 30 years in the future according to the current participant's dietary footprint. Results suggest that VR intervention decreased individual dietary footprints significantly more than the control condition. Aksel *et al.* [15] developed an educational VR game on waste management, improving the capability of sorting waste into a higher number of categories following the VR experience.

Differently from the previously mentioned works, in which the future dystopian representation and feedback are based on actual data, Hsu *et al.* [6] focused on the effects of exaggerated feedback intensifying the negative effects of water consumption and/or environmental damage, to provide more relevant and immediate information to users.

Results suggest that providing exaggerated feedback on water consumption in the environment evoked the highest levels of emotional response and pro-environmental attitude.

In this scenario, we proposed a Virtual Reality experience in a virtual reproduction of the city centre of Torino, allowing users to freely explore a familiar environment that might evoke an emotional impact on them. During the experience, the environmental conditions of the city gradually deteriorated through exaggerated and abstract visual feedback, suggesting the future effects of the climate emergency.

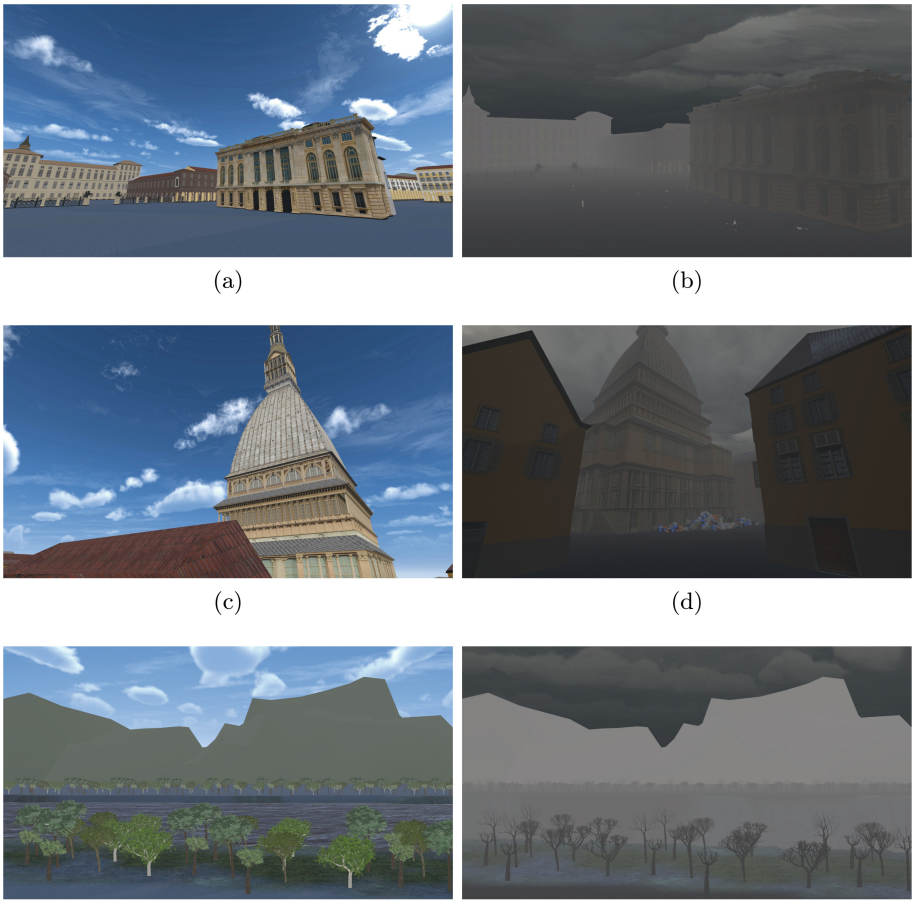

Fig. 2. Virtual reproduction of the city center of Torino, Italy, in which the experience takes place. The dystopian scenario is represented through visual effects.

3 Experiment

In this work, we investigated whether the visualization of a dystopian scenario had an emotional impact on users, and which visual effects best conveyed negative emotions in the users.

3.1 Setup

We developed a VR application using Autodesk Maya 2022[1] and Unity3D 2020.3[2]. The system uses HTC Vive Cosmos Elite[3] as HMD and runs on a Windows desktop computer with a Geforce RTX 30 series graphic card[4]. We started creating a 1:1 virtual reproduction of the centre of Torino, in Italy (Fig. 1), starting from a combination of data from Google Maps[5], Google Earth[6] and maps provided by the municipality archives. The virtual town was designed to have a photo-realistic look, but we still had to deal with some approximations, like random details around the scenario or rep repeated patterns (like the windows on the buildings). However, we payed special attention to the development of the main architectural structures and iconic landmarks of the city (Fig. 2a and 2b).

To simulate the worsening of the environmental conditions, we developed several visual and audio effects in the virtual environment (Table 1). To convey a direct emotional impact on users, we have opted for a more abstract and alternative representation of the effects of climate change, rather than just providing a data-driven representation. In particular, we defined three sets of effects, categorized on the basis of their target impact (Fig. 2):

A **Human Effects**, which impact on individuals (*pedestrians, smog*);
B **Urban effects**, which impact on the city (*trash, buildings*);
C **Naturalistic effects**, which impact on nature (*rivers, birds, trees*).

A description of the visual effects is provided in Table 1.

Table 1. Description of the VFX.

Human Effects (Castle Square)	
Pedestrians	They start coughing until they collapse to the ground
Smog	Cloud that blur the sight and masks the distant buildings
Urban effects (Mole Antonelliana)	
Trash	The area is covered with garbage.
Buildings	The facades of the buildings become darker and dirtied due to smog
Naturalistic effects (Near the river Po)	
Rivers	The Po's water level gradually drops until it dries up
Birds	They gradually fall to the ground
Trees	They gradually lose their leaves

[1] www.autodesk.it/products/maya/overview.
[2] www.unity.com/.
[3] https://www.vive.com/us/product/vive-cosmos-elite/overview/.
[4] https://www.nvidia.com/en-us/geforce/graphics-cards/30-series/.
[5] https://maps.google.com/.
[6] https://earth.google.com/.

Table 2. PANAS questionnaire, items are divided into positive and negative emotions.

Positive emotions	Negative emotions
1 Interested	2 Distressed
3 Excited	4 Upset
5 Strong	6 Guilty
9 Enthusiastic	7 Scared
10 Proud	8 Hostile
12 Alert	11 Irritable
14 Inspired	13 Ashamed
16 Determined	15 Nervous
17 Attentive	18 Jittery
19 Active	20 Afraid

3.2 Methods

We used a within-subjects approach, and the order of the effects per person was randomized. The experiment was carried out in one week. 15 subjects took part to the experiment, 11 men and 4 women, aged between 18–25 (40%), 26–40 (13%) and 40–60 (47%). All users but one live in the metropolitan area of Torino.

We used the following standard questionnaires:

- Positive and negative Affects (PANAS) [19] to quantify emotions (Table 2);
- Virtual Reality Neuroscience Questionnaire (VRNQ) [8] for the user experience (UX);
- Slater-Usoh-Steed (SUS) [17] for the sense of presence;
- Simulator Sickness Questionnaire (SSQ) [7] for cybersickness.

The PANAS questionnaire consists of 20 items, referring to 10 positive and 10 negative affects (or emotions), related to the feeling of the user. Each emotion is rated on a Likert scale from 1 to 5, based on how the users felt during the experience. 1 means "Not at all", 2 "Slightly", 3 "Moderately", 4 "Very" and 5 "Extremely". For every VFX, we calculated the mean values of the responses of the users, divided in ratings for positive emotions μ_p and for negative emotions μ_n. To validate the values, we then run a significance test (t-test) between the positive and negative emotional responses, for each VFX.

To evaluate the user experience, we used three questionnaires: VRNQ, SUS and SSQ. VRNQ questionnaire [8] consists of 20 statements, divided into 5 categories (User Experience, Game Mechanics, In-Game Assistance), and responses are given on a Likert scale from 1 to 7, where 1 stands for "extremely low" and 7 stands for "Extremely high". For the purpose of this experiment, we submitted only the first five items related to User Experience (Table 3). SUS questionnaire

[17] is related to the Sense of Presence, defined as the psychological feeling of being in a place (virtual or real) [14]. It consists of 6 items and the responses are given on a Likert scale ranging from 1 to 7, where 7 represents your normal experience of being in a place (Table 5). Finally, SSQ questionnaire [7] describes and assess simulator sickness. It consists of 16 items (symptoms) and responses are given on a scale from 0 to 3, where 0 means "None", 1 "Slight", 2 "Moderate" and 3 "Severe" (Table 4).

Table 3. VRNQ questionnaire. In this experiment, we submitted to users only the first five items related to User Experience

N	Question
User Experience	
1	What is the level of immersion you experienced?
2	What was your level of enjoyment of the VR experience?
3	How was the quality of the graphics?
4	How was the quality of the sound?
5	How was the quality of the VR technology overall (i.e. hardware & peripherals)?
Game Mechanics	
6	How easy was to use the navigation system (e.g. teleportation) in the virtual environment?
7	How easy was to physically move in the virtual environment?
8	How easy was to pick up and/or place items in the virtual environment?
9	How easy was to use items in the virtual environment?
In-Game Assistance	
10	How easy was to complete the tutorial(s)?
11	How helpful was/were the tutorial(s)?
12	How did you feel about the duration of the tutorial(s)?
13	How helpful were the in-game instructions for the task you needed to perform?
14	How helpful were the in-game prompts e.g. arrows showing the direction, or labels?
15	How easy was the 2-handed interaction e.g.,grab the tablet with the one hand, and push the button with the other hand?
VRISE	
15	Did you experience nausea?
16	Did you experience disorientation?
17	Did you experience dizziness?
18	Did you experience fatigue?
19	Did you experience instability?

Table 4. SSQ questionnaire

N	Question
1	General discomfort
2	Fatigue
3	Headache
4	Eye strain
5	Difficulty focusing
6	Increased salivation
7	Sweating
8	Nausea
9	Difficulty concentrating
10	Fullness of head
11	Blurred vision
12	Dizzy (eyes open)
13	Dizzy (eyes closed)
14	Vertigo
15	Stomach awareness
16	Burping

Table 5. SUS questionnaire.

N	Question
1	Please rate your sense of being in the virtual environment, on the following scale from 1 to 7, where 7 represents your normal experience of being in a place
2	To what extent were there times during the experience when the virtual environment was the reality for you?
3	When you think back about your experience, do you think of the virtual environment more as images that you saw, or more as somewhere that you visited?
4	During the time of the experience, which was strongest on the whole, your sense of being in the virtual environment, or of being elsewhere?
5	Consider your memory of being in the virtual environment. How similar in terms of the structure of the memory is this to the structure of the memory of other places you have been today? By "structure of the memory" consider things like the extent to which you have a visual memory of the virtual environment, whether that memory is in colour, the extent to which the memory seems vivid or realistic, its size, location in your imagination, the extent to which it is panoramic in your imagination, and other such structural elements
6	During the time of the experience, did you often think to yourself that you were actually in the virtual environment?

3.3 Protocol

Before starting, the operator collects the subjects' demographic data, including their age, gender, familiarity with VR and videogames, and whether or not they live in the Torino metropolitan area.

In case the user never experienced Virtual Reality, the operator provides a detailed explanation of the controllers and their functionalities, using a user-centered approach. After wearing the HMD, the user is teleported to a virtual world, specifically in Torino, in one of three distinct locations: Piazza Castello (Fig. 2b), along the Po river (Fig. 2e) or near the Mole Antonelliana (Fig. 2c). It is worth noting that the experiment takes place in Torino, so it is likely that the user has personally visited these places at least once and may have an emotional bond with them. When the actual experimental phase begins, the user explores the three selected locations in pleasant conditions reflecting a sunny day. The order in which the locations are visited is randomized, and the user has the freedom to move on to the next location at any time. Each location can be inspected for a maximum of three minutes. Following this, the subject is asked to visit again the previously shown locations in the same order but with different environmental conditions. In fact, the lighting in this phase suggests a grey and cloudy day in order to emphasize the phase change. In this case, each place is associated with a group of visual effects as follows:

- Castle Square: human effects
- Mole Antonelliana: urban effects
- Near the river Po: naturalistic effects

In this final phase of experimentation, between each location, the visual effects are temporarily removed for ten seconds to isolate the individual effects. As before, the user can explore each location for a maximum of three minutes. After trying every setup, users answer questionnaires regarding the level of emotional impact (PANAS), one for each VFX. At the end of the experiment, users filled out the questionnaires related to their overall experience (VRNQ, SUS, SSQ).

4 Results

4.1 Emotions

As mentioned, PANAS questionnaire was used to investigate the emotional impact of the visual effects on the participants. Since the user can rank each

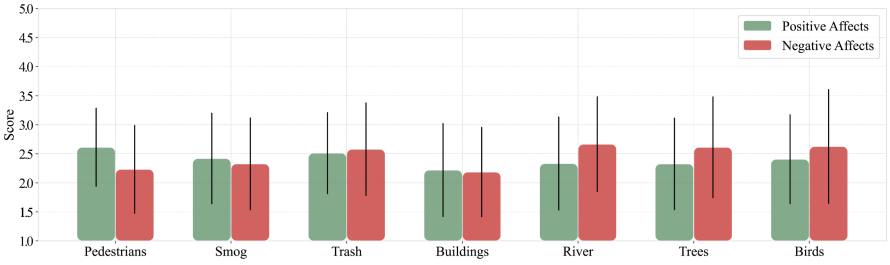

Fig. 3. Mean and standard deviation of the positive and negative emotions scores of PANAS divided by VFX.

statement from 1 to 5, a higher value corresponds to a more positive or negative emotional state.

As mentioned before, we divided the questionnaire items into positive and negative emotions for each VFX (Fig. 3), following the schema presented in Table 2). We then calculate mean and standard deviation of positive and negative emotions for each effect.

Regarding human effects (*pedestrians* and *smog*), positive emotions exceed negative emotions ($\mu_p = 2.61$ vs. $\mu_n = 2.23$ for *pedestrians* and $\mu_p = 2.42$ vs. $\mu_n = 2.32$ for *smog*). Similar results were observed for the *buildings* ($\mu_p = 2.22$ vs. $\mu_n = 2.19$).

However, the naturalistic effects and *trash*-related effects obtained a greater negative emotional impact compared to positive emotions ($\mu_p = 2.33$ vs. $\mu_n = 2.66$ for the *river*, $\mu_p = 2.41$ vs. $\mu_n = 2.63$ for the *birds*, $\mu_p = 2.33$ vs. $\mu_n = 2.61$ for the *trees*, and $\mu_p = 2.22$ vs. $\mu_n = 2.58$ for *trash*).

The results of the significance tests suggest that, only in the case of the *pedestrians* and the *river* VFX, the positive emotions are significantly different from negative ones ($t = 2.48, p < 0.05$ for *pedestrians* and $t = -2.15, p < 0.05$ for the *river*).

4.2 User Experience

Regarding user experience and Sense of Presence, the overall opinion was positive with mean values consistently higher than 4, on a Likert scale from 1 to 7, $\mu_{UX} \geq 4.93$; $\mu_{Presence} \geq 4.20$ (Fig. 4). Also, the system did not generally induce cybersickness. Although a few users reported difficulties related to vision, the mean values for these cases were acceptably low ($\mu \leq 0.75$). However, during the free-form interview with participants we discovered issues related to interaction and navigation. In the current status of the application, the interaction with the scene was mainly based on pushing buttons on the controllers. For example, using the joystick to rotate the user's head along the Y-axis led to feelings of dizziness and confusion.

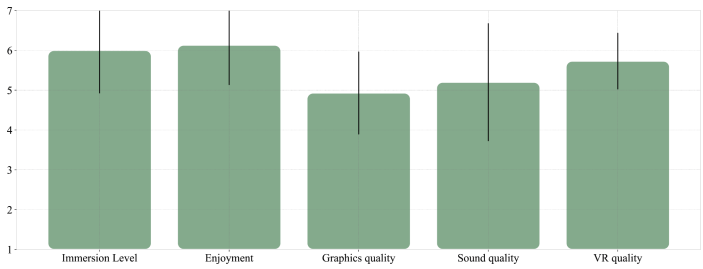

Fig. 4. Mean and standard deviation of the results of the User Experience in VRNQ questionnaire.

5 Discussion and Conclusions

We developed a VR experience aimed at educating and encouraging sustainable and pro-environmental behavior in people's daily lives. In particular, we presented an experiment that aims to quantify the emotional impact of the virtual environment and its visual effects.

As mentioned in the previous section, the exploration of the city center of Torino and the visualization of the VFX led to an emotional impact (**RQ1**). However, the intensity of the induced emotions depends on the group on VFX and NOT all visual effects induce mainly negative emotions. For example, *suffering pedestrians* seem to lead to positive emotions, maybe because the 3D models and movements looked too unrealistic and funny instead of scary.

Furthermore, both *smog* and *buildings* visual effects obtained unexpected emotional values, yet to a smaller degree than in the previous case. In fact, in both effects the positive emotions obtained higher values than negative emotions. Since the two effects are related, as the idea is that the facades of the buildings will be "dirtied" by smog, these results may depend on a misunderstanding of the visual effects.

Yet, naturalistic effects (*rivers, birds* and *trees*) obtained a higher prevalence of negative emotional impacts than positive ones, and they caused the highest negative emotional impact (**RQ2**).

However, it is worth noting that the distance between the positive and negative emotions subscale is very low in the majority of VFX, and results don't highlight a highly positive or negative emotional state ($\mu > 3$). Also, the significance test spot only two VFX (*pedestrians* and *river*) where the positive and negative emotions are significantly different. Since this experience has been carried out with the first version of the application, the framework may have been perceived as unclear by the participants, which may have influenced these results.

This experiment provided a positive assessment of the system's overall quality. Nevertheless, some users reported some difficulty in visual focusing and blurred vision. These effects could be related to the calibration of the HMD (Head-Mounted Display) or factors such as lens fogging. However, these effects do not cause physical discomfort, but rather affect an ideal simulation experience.

In summary, this experiment helped us identify several aspects that require review and improvement for the future development of the project:

- avoid using *pedestrians* visual effects as they did not have the desired impact on participants;
- extend *trash* visual effect to cover the entire city;
- improve UX and interaction design to create a more engaging and easy-to-use experience.

5.1 Future Work

As a work in progress, we are developing a virtual house with furniture and household appliances. In this experiment, participants are asked to interact with household appliances in the virtual home. Each action in the virtual house modifies the environmental condition of Torino, by activating an improved version of the presented VFX. This extension aims to investigate how the cause-effect relationship between actions within the room and the worsening of the surrounding virtual environment conditions modifies perceptions of a catastrophic future and the VFX emotional impact.

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