The Impact of Immersive Visualization on Engagement and Emotions Elicitation

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ABSTRACT

The power of environments to elicit emotions in humans has been widely studied in experimental psychology by using exposure to photographs or real situations. Also, many studies showed the ability of movies and imagery techniques to arouse emotions. To this aim, giant strides have been made with the development of Virtual Reality (VR), currently considered one of the most powerful tools to experimentally investigate the effect of environments on the emotions' elicitation by human beings. This is attributed to its capacity to provide simulated experiences that induce a *sense of being* in the real world. Furthermore, the immersive feature of VR, promoting a sense of presence within virtual scenarios, coupled with emotions' elicitation, has given rise to a clinical-therapeutic application of VR, especially in the treatment of anxiety disorders. This research study, conceived by HOPE (Humanitarian Operators Psychological E-services), aligns with the broader scope of the project to use VR as an effective medium for PTSD treatment of humanitarian operators, employing a specific protocol composed of virtual war and naturalistic scenarios. To this purpose, a sample of 42 participants was used to explore the general research objectives of this study that refer to the validation of four VR natural scenarios and nine VR war scenarios, assessing their impact in emotional states in terms of valence, arousal, control and engagement; as well as evaluating potential differences between natural and war scenarios in the emotional states' ratings.

Keywords: virtual reality; immersive visualization; emotions elicitation

1 Introduction

The power of environments to elicit emotions in humans has been widely studied in experimental psychology by using exposure to photographs or real situations. Also, many studies showed the ability of movies and imagery techniques to arouse emotions [1]. To this aim, giant strides have been made with the development of Virtual Reality (VR), currently considered one of the most powerful tools to experimentally investigate the effect of environments on the emotions' elicitation by human beings [2]. This is attributed to its capacity to provide simulated experiences that induce a *sense of being* in the real world [3; 4]. Moreover, the ability to simulate environments challenging to represent in the physical world has empowered researchers to study these scenarios in controlled laboratory conditions, analyzing individual reactions and easily and economically isolating and modifying variables—an operation considered unfeasible in real-world spaces [5; 6]. Furthermore, the immersive feature of VR, promoting a sense of presence within virtual scenarios [7], coupled with emotion elicitation, has given rise to a clinical-therapeutic application of VR, especially in the treatment of anxiety disorders. Through gradual exposure to traumatic stimuli, virtual experiences, employed as psychotherapeutic tools, can guide individuals in desensitizing progressively from trauma and improving their response to crisis situations [8; 9]. For this reason, VR is already considered the first-line treatment for Post-Traumatic Stress Disorder (PTSD) [10]. This research study, conceived by

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HOPE (Humanitarian Operators Psychological E-services), which is led by Professor Alessandra Talamo, aligns with the broader scope of the project to use VR as an effective medium for PTSD treatment of humanitarian operators, employing a specific protocol composed of virtual war and naturalistic scenarios.

To this purpose, the general research objectives of this study include: the validation of four VR natural scenarios, assessing their impact in emotional states in terms of valence, arousal, control and engagement; the validation of nine VR war scenarios, examining their effect on emotional states in terms of valence, arousal, control and engagement; and the evaluation of differences in the assessment of emotional states between natural and war scenarios.

2 Materials and Methods

This study employed a within-subjects study design, to examine the influence of VR natural environments and war situations on individuals' engagement and affective experience, in order to validate the use of these virtual stimuli. A posttest-only design was used to evaluate the effects of natural and war scenarios, by asking participants to rate their emotional experience, after the exploration of each of them (refer to the ***Procedure section***, for the full description).

Participants were recruited in March 2023, through referrals, community flyers, and university web listings advertising the possibility to experience Virtual Reality. We screened 111 individuals who completed the recruitment survey, based upon the study inclusion/exclusion criteria. The exclusion criterion was to have a history of trauma related to violent events and related to the theme of armed conflict and/or having hypothesized a disturbing reaction to deal with images linked to war scenarios (for details, see Measures section). In total, the sample consisted of 42 participants who were retained for the experiment and were invited to participate in an in-person experimental session between March and June 2023. Among them, 11 were male and 31 were female, ranging between 20-31, with a mean age of $M = 24.33$ ($SD = 2.32$). Concerning occupational status, the majority were university students (81%), with some exceptions (workers: 17%). About the educational level, most of the participants had a Bachelor degree (64 %) or a Master degree (21%), and some of them hold a high school diploma (14%). The study was approved by the Ethical Commission of the Sapienza University of Rome (CERT_18AB2606A20). Participation was voluntary, without any compensation.

2.1 Procedure

Participants that met the eligibility criteria were contacted to confirm their participation and schedule the experimental session. The experiment took place in the room of the IDEaCT Social Lab, which is part of the Department of Developmental and Social Psychology of Sapienza, University of Rome. After the participants entered the laboratory, they were asked to read and sign the informed consent and were fitted with the Polar H10 heart rate belt that captured the participants heart rate. Then, the researcher gave participants the Oculus Quest 2, the standalone VR system that consists of an HMD and two controllers, and gave instructions on using the VR system. At that moment, the recording of the experimental session started, registering: the room to check participants' behaviors and the mirroring of the VR device (see **Figure 1**). Also, participants were instructed by the researchers on how to perform the controlled breathing technique, which they were asked to do if their physiological data indicated a high level of stress across the experimental session.

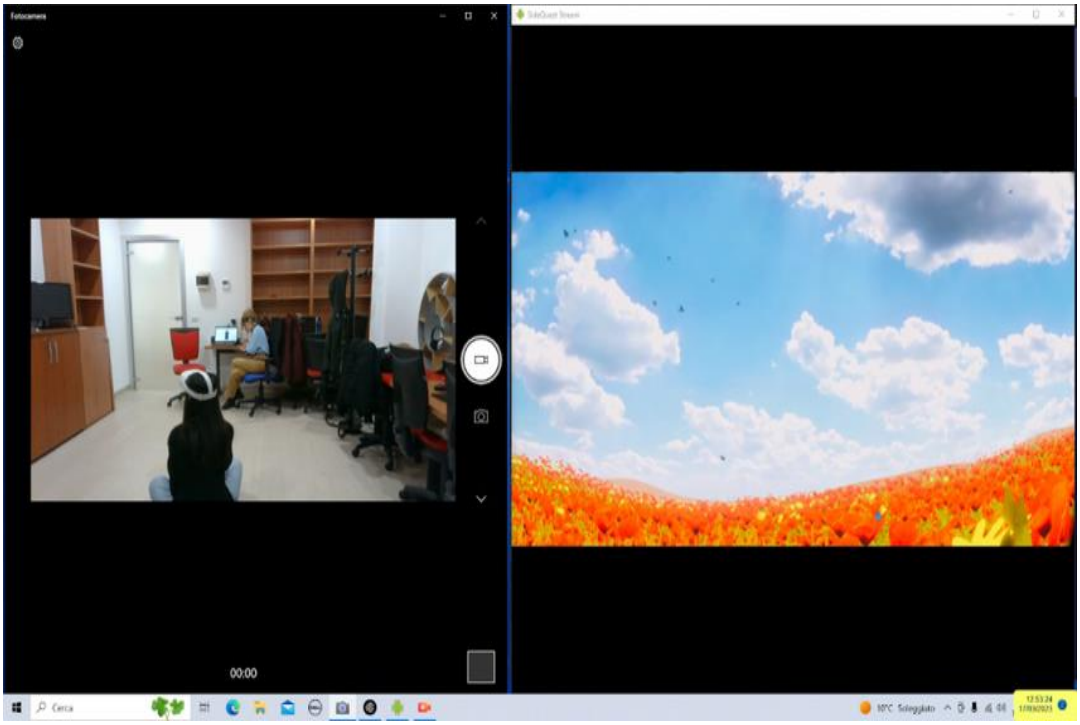

Figure 1. *Screenshot of the experimental session.*

Following the brief training, the experiment will start. Participants were instructed to select each scenario and to explore the surrounding environment, moving freely in the space and looking at what was around them.

First, participants explored the natural scenarios, in the following order: (a) tropical island scenario (b) tropical beach scenario; (c) meadow scenario; (d) forest scenario (see **Appendix 1**). After exploring each of the virtual scenarios for 2 minutes, participants were asked to select a button, where the post-tests were inserted (SAM). Participants completed the questionnaire directly in the virtual reality. Once participants have explored and assessed all the four natural scenarios, they will be asked to select their preferred environment that they will use as "comfort area" in the subsequent part of the experiment. Then, participants started the experience with the war scenarios, in the following order: (a) party; (b) war shelter; (c) medical camp; (d) wreckage; (e) mass graves; (f) crossfire; (g) hostages; (h) guerilla; (i) gunpoint. Participants entered the first viewpoint of the scenarios (refer to **Appendix 2**). In some of the scenarios, they also had the possibility to move around and shift in other viewpoints, clicking the travel points located in the scenario.

After each of the war scenarios, participants were required to evaluate their emotional states (SAM). Following each of the war scenarios, participants returned to the natural scenario that they priorly selected as their preferred one and stayed there for about two minutes. After that, researchers checked participants' heart rate and if the parameters indicated that participants were still experiencing a high level of stress, they were asked to perform the controlled breathing technique. This was done to return participants to their emotional baseline and prevent a cumulative effect in the evaluation of subsequent war scenarios. The same procedure was repeated for all the nine war scenarios. No randomization of all the virtual scenarios' order was adopted, since the scenarios were elaborated with a hypothesized increased levels of activation, engagement, and perception of risks. The main procedure is graphically presented in **Figure 2.**

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Figure 2. *Schematic experimental procedure adopted for the study.*

2.2 Virtual scenarios

Virtual scenarios were developed by an Italian company (IDEGO Digital Psychology), which has fostered several projects in the areas of e-Health and Virtual Reality, in order to support the practice of psychologists, psychotherapists and other professionals, working in the fields of mental health, psychotherapeutic practice and psychiatric rehabilitation. For the aim of the present work, 13 virtual scenarios have been created, considering ecological criteria for the design of VR [11; 12; 13; 14; 15; 16]: 4 are natural scenarios, and 9 are scenarios concerning war situations. The virtual experience was offered through the Oculus Meta Quest 2.

Natural scenarios were created by adopting the ten components of the *Biophilic Quality Index* (sunlight, color, gravity, fractals, curves, detail, water, life, representation of nature and organized complexity), that are associated with the condition of relaxation and recovery from stress, as consequence of the regenerative environment. Specifically, the four scenarios represent: (a) tropical island scenario (b) tropical beach scenario; (c) meadow scenario; (d) forest scenario. Selected photos of the four environmental settings of the natural scenarios in virtual reality videos are presented in **Appendix 1**. Further details about the features of the natural scenarios are reported in **Appendix 3**.

The nine war scenarios were designed with the clinical expertise developed at the HOPE psychological support services (Humanitarian Operators Psychological E-services), based on traumatic experiences reported by professionals working in conflict zones. These war scenarios represent nine different situations related to armed conflicts: (a) party; (b) war shelter; (c) medical camp; (d) wreckage; (e) mass graves; (f) crossfire; (g) hostages; (h) guerilla; (i) gunpoint. **Appendix 2** shows selected photos of the nine environmental settings of the war scenarios in virtual reality videos. The war scenarios concern different stress induction and triggering activation, varying in terms of locations, possibility of action (viewpoints), presence of other people and sounds. Further details about war scenarios' characteristics are provided in **Appendix 4**.

2.3 Measures

In the recruitment survey, participants were asked to complete a number of questions concerning socio-demographic indicators (i.e., gender, age, highest level of educational achievement, country of birth, employment status), prior experience with video-games and virtual reality (frequency of use and types of games), and their level of connection with nature.

Screening questions addressed war-related traumas and expected negative reactions to war-related content. Participants were queried about personal war traumas or memories related to armed conflict (yes/no). Additionally, they reported the disturbance level experienced when witnessing war scenes through various media and anticipated discomfort in a virtual reality war simulation (rated from 1 = not at all to 5 = very much). If a participant reported war traumas and indicated high anticipated discomfort (4= quite a bit, or 5= very much), they were excluded from the study. Participants were also screened for other prior traumatic experiences using the adapted Harvard Trauma Questionnaire [HTQ, 17; HTQ-I and HTQ-IV]. If participants reported experiencing at least one traumatic event, they were excluded from the study.

To measure participants' emotional state after the experience of the VR scenario, an adapted version of the Self-Assessment Manikin scale [SAM; 18] was adopted. The SAM is a pictorial scale, widely used for the assessment of emotional states, in terms of valence (happy – sad), arousal (calm – activated) and in control (out of control – in control). A further dimension was added in the scale to assess the degree of engagement in the VR scenario (engaged – not engaged). The four components will be considered separately in the analyses. Participants were asked to indicate their emotions on the 5-point rating scale (see **Figure 3**).

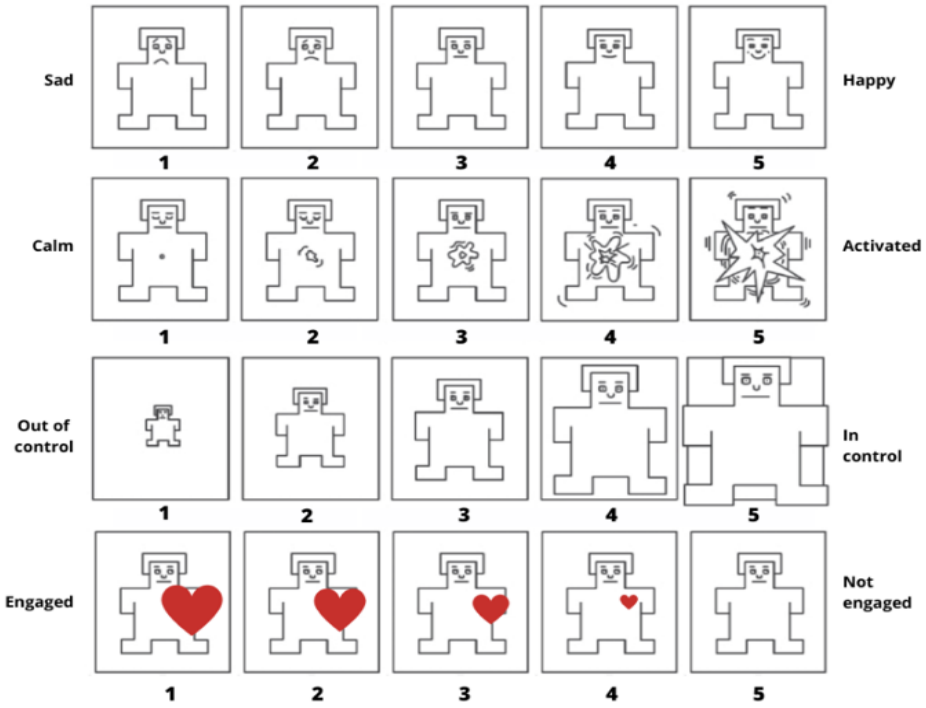

Figure 3. *Self-Assessment Manikin scale for the assessment of valence, arousal, control, and engagement used in VR.*
Note. *English translation from the Italian version used in the study.*

3 Results

3.1 Validation of virtual Natural scenarios

Table 1 shows means and standard deviations of the four components of SAM for each of the natural scenarios. About the *valence* component, descriptive measures indicate that the meadow scenario received the highest scores in inducing positive emotions, whereas the tropical beach was the worst. About the *arousal* component, descriptive measures show that the tropical island scenario received the highest scores in inducing arousal, whereas the tropical beach emerges as the worst. Moreover, descriptive measures indicate that the highest scores for the *control* component is perceived in the forest scenario, while the lowest

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scores in the tropical beach. Finally, regarding the engagement component, the forest scenario emerged as the most engaging, whereas the tropical beach was the worst.

Table 1. *Descriptives of SAM for natural scenarios.*

Scenarios	Valence		Arousal		Control		Engagement	
	M	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
Tropical island	4.00	.83	2.33	1.32	3.64	1.08	3.62	.85
Tropical beach	3.69	.90	1.81	.83	3.33	1.20	3.18	1.15
Meadow	4.24	.96	1.90	1.12	3.86	1.00	4.12	.86
Forest	4.14	.87	1.93	1.14	3.88	1.04	3.71	1.02

As can be seen in **Table 1**, arousal, compared to all other emotional states considered in SAM, is the lowest rated. In fact, the averages between scenario type and arousal turn out to be the lowest. With respect to valence, the scenario that obtained the highest score is meadow, followed by forest, tropical island, and finally tropical beach. The control dimension reports quite similar values across the four natural scenarios. In the end, engagement is the dimension that varies the most, where meadow emerges as the most engaging, followed by forest, tropical island and tropical beach. A repeated measures ANOVA was used to explore the differences in the four emotional states' scores of the participants in the four natural virtual scenarios.

Results showed a significant interaction effect between emotional states (SAM components) and natural scenarios; F (9, 41) = 2.85, p = 0.003, $\eta 2$ = .013. **Figure 4** presents the interaction plot (SAM * Natural scenarios) of the evaluation for the natural scenarios on the different emotional states.

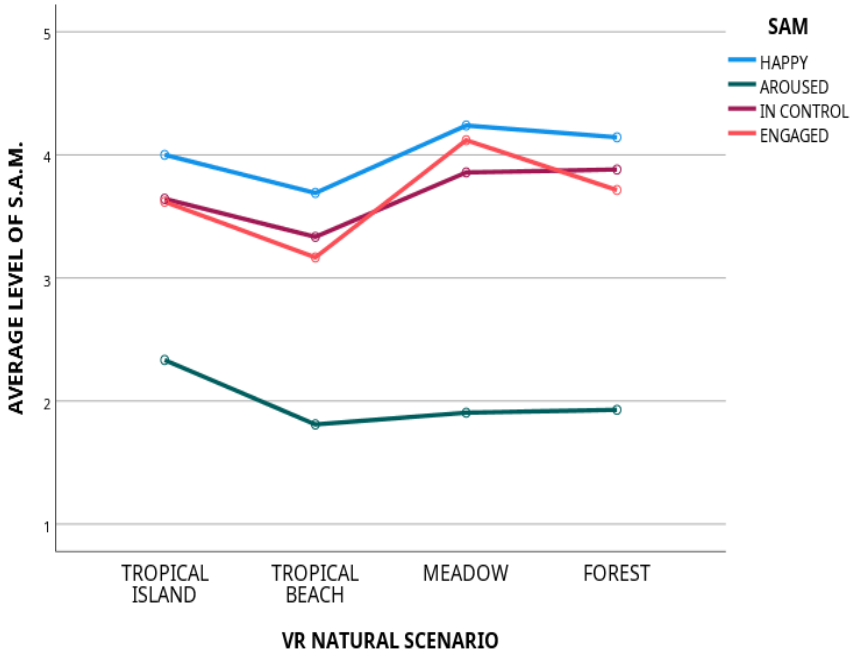

Figure 4. *Interaction plots of estimated marginal means of participant ratings across the four natural scenarios and the different emotional states.*

Results from the post-hoc analysis, focusing exclusively on comparisons between natural scenarios across each emotional states' component, showed that the only significant difference was between tropical beach and meadow in terms of engagement, *mean diff.* = -.95, t (41) = -5.59, *ptukey* <.001, meaning that tropical beach scenario was considered less engaging compared to the meadow scenario.

3.2 Validation of virtual War scenarios

Table 2 represents means and standard deviations of the four components of SAM for each of the war scenarios.

Table 2 *Descriptives of SAM for war scenarios.*

Scenarios	Valence		Arousal		Control		Engagement	
	M	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
Party	3.36	.85	2.90	1.08	3.64	1.19	3.36	1.10
War shelter	2.31	.68	3.29	.84	2.40	1.25	3.33	.87
Medical camp	1.90	.69	3.07	1.07	1.93	1.16	3.45	.92
Wreckage	1.55	.71	3.64	.82	1.90	1.03	3.83	.85
Mass graves	1.45	.63	3.10	1.03	2.02	1.14	3.79	.78
Crossfire	1.86	.71	3.64	.88	1.81	.92	3.81	.77
Hostages	1.95	.89	3.38	1.04	1.57	.91	3.67	.82
Guerrilla	1.76	.73	4.45	.74	1.64	.79	4.38	.66
Gunpoint	2.07	.78	3.45	1.06	1.69	.98	3.86	.81

About the *valence* component, descriptive measures indicate that the party scenario received the highest scores in inducing positive emotions, whereas the mass graves was the worst. About the *arousal* component, descriptive measures show that the guerrilla scenario received the highest scores in inducing arousal, whereas the party emerges as the worst. Moreover, descriptive measures indicate that the highest scores for the *control* component is perceived in the party scenario, while the lowest scores in the hostages. Finally, regarding the engagement component, the guerrilla scenario emerged as the most engaging, whereas the war shelter was the worst.

A repeated measures ANOVA was carried out to investigate the differences in the four emotional states' scores of the participants in the nine war virtual scenarios. Results demonstrated a significant interaction effect between SAM and war scenarios; F (24, 41) = 22.4, p < .001, $\eta 2$ = .111. **Figure 5** presents the interaction plot (SAM * War scenarios) of the evaluation for the nine war scenarios on the different emotional states.

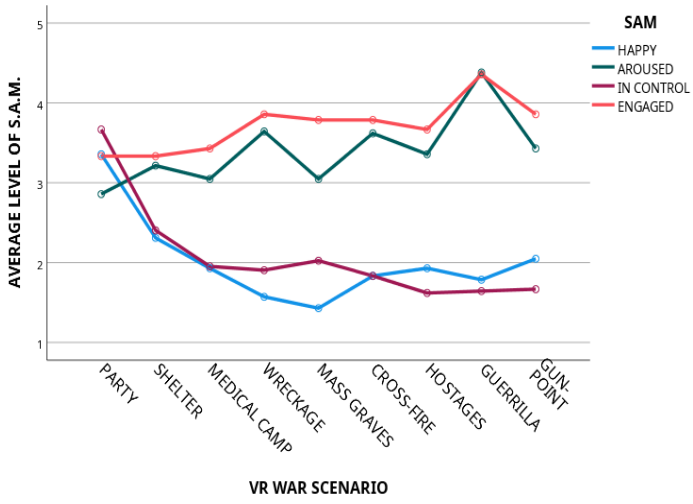

Figure 5. *Interaction plots of estimated marginal means of participant ratings across the nine war scenarios and the different emotional states.*

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Post-hoc pairwise comparisons were conducted to further investigate this effect. Concerning the **valence** component, results showed that the party scenario was rated significantly higher compared to all the other war scenarios; specifically: shelter, *mean diff.* = 1.07, *t* (40) = 6.81, *ptukey* <.001, medical camp, *mean diff.* = 1.46, *t* (40) = 8.37, *ptukey* <.001, wrackage, *mean diff.* = 1.81, *t* (40) = 9.91, *ptukey* <.001, mass graves, *mean diff.* = 1.93, *t* (40) = 11.41, *ptukey* <.001, crossfire, *mean diff.* = 1.51, *t* (40) = 9.65, *ptukey* <.001, hostages, *mean diff.* = 1.42, *t* (40) = 7.80, *ptukey* <.001, guerrilla, *mean diff.* = 1.61, *t* (40) = 10.34, *ptukey* <.001, and gunpoint, *mean diff.* = 1.32, *t* (40) = 7.63, *ptukey* <.001. Moreover, the shelter scenario was considered significantly higher in valence compared to the wreckage, *mean diff.* = .73, *t* (40) = 6.62, *ptukey* <.001, and the mass graves scenarios, *mean diff.* = .85, *t* (40) = 6.64, *ptukey* <.001. Also, the medical camp scenario was rated higher in valence compared to the mass graves scenario, *mean diff.* = .46, *t* (40) = 4.18, *ptukey* = .045; and mass graves scenario was also considered lower in valence compared to the gunpoint scenario, *mean diff.* = -.61, *t* (40) = -4.53, *ptukey* = .018.

With regards to the **arousal** component, post-hoc comparisons indicated that the party scenario was rated as less arousing compared to the wreckage, *mean diff.* = -.78, *t* (40) = -4.82, *ptukey* =.008; the crossfire, *mean diff.* = -.76, *t* (40) = -4.64, *ptukey* =.013; and the guerrilla scenarios, *mean diff.* = -1.54, *t* (40) = -8.61, *ptukey* <.001. Moreover, results showed that the guerrilla scenario was rated with higher levels of arousal compared to the following scenarios: shelter, *mean diff.* = -1.17, *t* (40) = -8.41, *ptukey* <.001; medical camp, *mean diff.* = -1.34, *t* (40) = -8.68, *ptukey* <.001; wreckage, *mean diff.* = -.76, *t* (40) = -7.76, *ptukey* <.001; mass graves, *mean diff.* = -1.34, *t* (40) = -8.08, *ptukey* <.001; crossfire, *mean diff.* = -.78, *t* (40) = -8.15, *ptukey* <.001; hostages, *mean diff.* = -1.02, *t* (40) = -7.99, *ptukey* <.001; and gunpoint, *mean diff.* = -.95, *t* (40) = -6.43, *ptukey* <.001. Other significant differences were found between medical camp and wreckage, where medical camp was rated as less arousing compared to the wreckage scenario, *mean diff.* = -.59, *t* (40) = -4.84, *ptukey* = .007, and between wreckage and mass graves, with higher ratings of arousal in the wreckage scenario, *mean diff.* = .59, *t* (40) = 4.65, *ptukey* =.013.

About the **control** component, findings showed that participants felt significantly higher control in the party scenario than in all the other war scenarios; specifically: shelter, *mean diff.* = 1.27, *t* (40) = 6.63, *ptukey* <.001, medical camp, *mean diff.* = 1.76, *t* (40) = 7.35, *ptukey* <.001, wrackage, *mean diff.* = 1.76, *t* (40) = 8.53, *ptukey* <.001, mass graves, *mean diff.* = 1.66, *t* (40) = 8.59, *ptukey* <.001, crossfire, *mean diff.* = 1.85, *t* (40) = 9.16, *ptukey* <.001, hostages, *mean diff.* = 2.07, *t* (40) = 9.23, *ptukey* <.001, guerrilla, *mean diff.* = 2.02, *t* (40) = 10.50, *ptukey* <.001, and gunpoint, *mean diff.* = 1.98, *t* (40) = 9.92, *ptukey* <.001. Also, a statistically significant difference was found between the shelter and hostages scenarios, where the shelter scenario was rated higher in control compared to the hostages scenario, *mean diff.* = .81, *t* (40) = 4.68, *ptukey* = .012.

Finally, concerning the last SAM component of **engagement**, post-hoc comparisons demonstrated that participants reported statistically significant higher levels of engagement in the guerrilla scenarios compared to the following scenarios: party, *mean diff.* = -1.02, *t* (40) = -5.50, *ptukey* = .001; shelter, *mean diff.* = -1.02, *t* (40) = -6.48, *ptukey* <.001; medical camp, *mean diff.* = -.93, *t* (40) = -6.36, *ptukey* <.001; mass graves, *mean diff.* = -.59, *t* (40) = -4.33, *ptukey* = .030; crossfire; *mean diff.* = -.56, *t* (40) = -4.45, *ptukey* = .022; and hostages, *mean diff.* = -.71, *t* (40) = -4.88, *ptukey* = .007.

3.3 Comparison between overall ratings for Natural and War scenarios

Table 3 presents means and standard deviations of the four components of SAM for the overall ratings of natural and war scenarios, obtained through the means of all the scenarios within the two types.

Table 3. *Descriptives of SAM for overall nature and war scenarios.*

Scenarios	Valence		Arousal		Control		Engagement	
	M	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
Natural scenarios	4.02	.67	1.99	.80	3.68	.85	3.65	.66
War scenarios	2.02	.46	3.44	.68	2.07	.77	3.72	.528

A repeated measures ANOVA was conducted to explore the differences in the four emotional states' scores of the participants across the two types of virtual scenarios. Results demonstrated a significant interaction effect between SAM components and type of scenarios; F (3, 41) = 185.2, p < .001, $\eta 2$ = .414. **Figure 6** presents the interaction plot (SAM * Type of scenario) of the overall evaluation for the natural and war scenarios on the different emotional states.

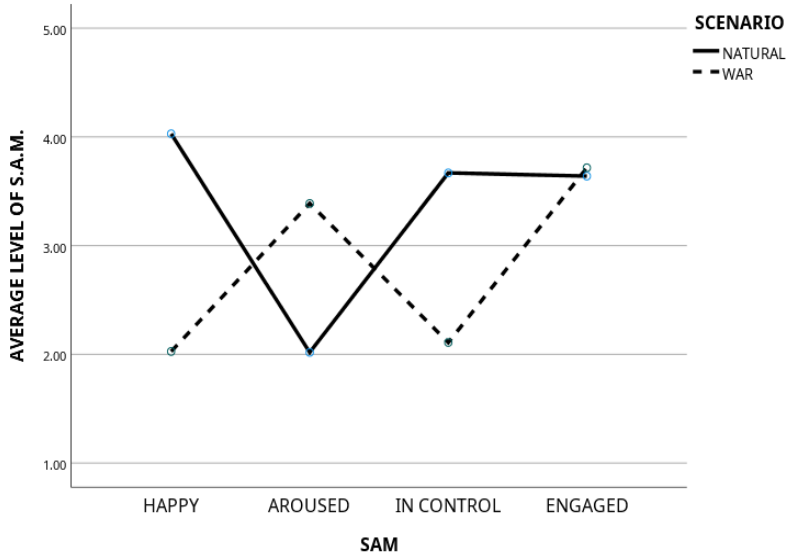

Figure 6. *Interaction plots of estimated marginal means of participant overall ratings for natural and war scenarios and the different emotional states.*

Findings from the post-hoc comparison showed significant differences between natural and war scenarios in all the emotional states. Specifically, compared to the war scenarios, natural scenarios were rated: significantly higher in happiness, *mean diff.* = 1.99, *t* (41) = 18.15, *ptukey* <.001, and control, *mean diff.* = -1.44, *t* (41) = -9.76, *ptukey* <.001, and lower in terms of arousal, *mean diff.* = 1.61, *t* (41) =13.06, *ptukey* <.001. No significant differences between the two kinds of scenarios were found in terms of engagement, *mean diff.* = -0.07, *t* (41) = -.75, *ptukey* = .995, indicating that both natural and war scenarios were perceived equally engaging for participants.

4 Discussion

Regarding the validation of the four virtual Natural scenarios, noteworthy findings have emerged. Specifically, the scores pertaining to all SAM components (valence, arousal, control, and engagement) within the tropical beach are lower compared to the values observed in the other natural scenarios. Possible interpretations of these results could refer to: the excessive *similarity* respect to the tropical island scenario that, according to the experimental procedure, was explored previously; the lower *biodiversity*, meaning the variety of flora and fauna, compared to the other natural scenarios; the *lack of natural sounds*, such as birds chirping and the sound of water, that are usually associated with a relaxed condition, and therefore, with positive feelings and emotions.

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Regarding the validation of the nine virtual War scenarios, an interesting aspect emerged with respect to the general trend of the four SAM components. In line with our expectations, two main trends can be observed: one *downward* trend, involving the valence and control components, indicating that the order in which the war scenarios were presented generally corresponds to an order of increasing elicitation of negative emotions; the other with an *upward* trend, involving the arousal and engagement components, showing that the order in which the war scenarios were presented generally corresponds to an order of increasing emotional activation.

However, despite the overall uniformity of the two general trends, fluctuations, both upward and downward, are evident, particularly in arousal and engagement. This more erratic pattern can be explained by the level of spatial audio, a crucial factor highlighted in existing literature for generating engagement.

Overall, emotional states' ratings of the two types of scenarios are in line with the general literature on the topic. In relation to emotional valence and arousal, natural scenarios elicited more positive reactions characterized by low arousal, while war scenarios were rated with more negative emotions and higher arousal. These results align with prior research that extensively established the positive effects of exposure to both real and virtual natural stimuli in enhancing positive emotions and promoting feelings of relaxation [e.g., 19; 20]. On the contrary, it was expected that war scenarios would elicit more negative reactions due to the potentially distressing and emotionally charged nature of their content and the presence of elements that may provoke discomfort, fear, or heightened arousal, contrasting with the positive and calming qualities attributed to natural stimuli.

In terms of control perception, participants reported a higher sense of control in natural scenarios and a lower level in war scenarios. This aligns with previous findings suggesting a consistent pattern of lower perceived control in scenarios characterized by negative emotions (e.g., sadness, anger, fear, and disgust) compared to those associated with positive or neutral emotions [21]. The observed trend in control perception reinforces the connection between emotional valence and the perception of control, highlighting the inter-correlated role of different emotional aspects on individuals' subjective experiences in virtual scenarios. Finally, concerning the engagement component, both natural and war scenarios demonstrated a comparable and high level of engagement, indicating the effectiveness of all the virtual scenarios in eliciting immersive responses in participants, beyond the specific contents.

5 Conclusions

This study contributes to the understanding of virtual scenarios capacity to elicit different kind of emotions. In particular, validation of both natural and war scenarios was provided within this research. Overall, the results showed that natural scenarios evoked positive reactions characterized by low arousal, positive valence, high control and a high level of engagement. These results align with previous research emphasizing the positive effects of exposure to natural environments. On the other hand, results indicated that war scenarios elicited more negative reactions with higher arousal, negative valence, lower control and a similar level of engagement with respect to natural scenarios, indicating the effectiveness of both the categories of virtual scenarios in eliciting immersive responses in participants, beyond the specific contents. These findings are consistent with our expectations and the broader literature on the topic.

6 Declarations

6.1 Competing Interests

The authors have no conflicts of interest to declare that are relevant to the content of this article.

6.2 Acknowledgements

A huge thanks to IDEaCT Social Lab research team and to all the participants, without whom this research would have been impossible, and to IDEGO for their fundamental contribution in the development of VR scenarios.

6.3 Study Limitations

The study's methodology carries certain limitations that warrant consideration. One notable constraint is the absence of randomization in presenting natural and war scenarios, potentially impacting participants' perception and evaluation. While this non-random approach was chosen to ensure a specific order reflecting increasing negative, arousing, and triggering content in the war scenarios, it introduces a potential source of bias. Additionally, the study adopted a convenience sample, limited to participants aged 18 to 35, that may raise concerns about the results' generalizability. The skewed gender distribution, with a majority of participants being women, further emphasizes the need for caution when generalizing findings to a broader population. These limitations underscore the importance of interpreting the results within the specific context of the study's design and participant characteristics and highlights the need for further research and testing.

6.4 Ethical Approval

The study was approved by the Ethical Commission of the Sapienza University of Rome (CERT_18AB2606A20). Participation was voluntary, without any compensation.

6.5 Informed Consent

Informed consent was obtained from all individual participants included in the study at the initial stage of the research process.

6.6 Publisher’s Note

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Appendix 1.

(A)

(B)

(C)

(D)

Appendix 1. Selected photos of the four nature environment settings in virtual reality videos: (a) tropical island scenario (b) tropical beach scenario; (c) meadow scenario; (d) forest scenario.

Appendix 2.

(A)

(B)

(C)

(D)

(E)

(F)

(G)

(H)

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(I)

Appendix 2. Selected photos of the nine war scenario settings in virtual reality videos: (a) party; (b) war shelter; (c) medical camp; (d) wreckage; (e) mass graves; (f) crossfire; (g) hostages; (h) guerilla; (i) gunpoint.

Appendix 3.

	Scenario	**Greenery**	**Water**	**Animals**	**Sounds**
A	Tropical island	Tropical beach trees	Total visibility of the ocean and waves	Fishes, birds	Flowing water, rushing water, wave
B	Tropical beach	Tropical beach trees	Expansive visibility to ocean	Fishes, birds	Flowing water, rushing water, wave
C	Meadow	Field of poppies and meadow	X	Butterflies, birds	Bird song, leaves rustling, insects
D	Forest	Nondescript conifers, nondescript rainforest trees, bushes and moss	Moderate visibility to the river	Butterflies, birds, fishes	Bird song, flowing water, leaves rustling, insects

Appendix 3. Description of the natural scenarios
Note. X = none shown in the scenario.

Appendix 4.

	Scenario	Location	Viewpoints	Presence of people	Sounds
A	Party	Indoor space (house)	3 viewpoints	Four persons talking and dancing	Music, sound of uncorking a bottle, fireworks
B	War shelter	Indoor space (bunker)	1 viewpoint	X	Explosions, gunshots
C	Medical camp	Semi-open space, rural context	1 viewpoint	Two injured people in pain lying on the beds	Moans, noise of planes in the distance
D	Wreckage	Outdoor space, urban context	4 viewpoints	Corpses on the ground, animal carcasses	Explosions, fires, sirens
E	Mass graves	Outdoor space, rural context	3 viewpoints	X	Tolling of a bell, noise of planes in the distance
F	Crossfire	Outdoor space, urban context	3 viewpoints	Wounded and dead bodies on the ground	Explosions, gunshots
G	Hostages	Semi-open space, rural context	1 viewpoint	Armed soldier and two hostages	Soft moans and the sound of gunfire in the distance
H	Guerilla	Outdoor space, urban context	3 viewpoints	Four soldiers shooting	Gunshots and harrowing screams
I	Gunpoint	Semi-open space, rural context	1 viewpoint	Two armed soldiers and two hostages	Soft moans and the sound of gunfire in the distance

Appendix 4. Description of the war scenarios
Note. X = none presented in the scenario.

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