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Research article

An attention-based approach for assessing the effectiveness of emotion-evoking in immersive environment

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ABSTRACT

Visual stimuli within an immersive virtual environment impact human perception and behavior in notably different ways compared to the real world. Previous studies have presented evidence indicating that individuals in various emotional states exhibit an unconscious attentional bias toward either positive or negative stimuli. However, whether these findings can be replicated within an immersive virtual environment remains uncertain. In this study, we devised an attention-based experiment to explore whether the correlation between participants' emotional states and the valence of visual stimuli influences their attentional bias. Participants (n = 28) viewed 360-degree videos with varying valence levels (positive and negative) to evoke emotions. Subsequently, we utilized standard emotional human faces as stimuli to assess how the consistency in video valence and emotional faces affects reaction time (RT) in Go tasks and error rates in No-go tasks. We employed the Ex-Gaussian approach to analyze the RT data. The parameters—mu (μ), sigma (σ), and tau (τ)—were computed to denote response speed and attentional lapses, respectively. Our findings revealed a significant increase in tau (τ) when the valence of the video and emotional faces aligned. This suggests that the Go/No-go paradigm is effective in evaluating the impact of emotion-evoking stimuli within an immersive environment.

1. Introduction

In recent years, researchers across various fields have embraced Virtual Reality (VR) technology to tackle challenging research scenarios that demand high ecological validity. These scenarios encompass quantitative studies in social interaction [53], the measurement of individual defense space [34], the degree of quantification of expressions [24], elderly care, and assistance for individuals with disabilities [7,29]. In the realm of psychology, VR is gaining ground as a method to improve the generalizability of experimental findings, maintain control over stimuli, and improve the reproducibility of procedures [30].

Emotion plays an essential role in understanding human-computer interaction [6,11,25]. VR-related products such as 360-degree videos and VR games have found broad applicability in emotion research, creating fully immersive environments for conducting experiments [8,23,32]. Past studies have indicated the efficacy of 360-degree videos in evoking various emotions [22,52], including

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complex emotions such as awe and gratitude [4,5]. Given the significant influence of emotion on decision-making and human behavior, it is crucial to understand the underlying mechanisms of emotion-evoking [9,21]. A comprehensive understanding of these mechanisms can aid in tailoring media content to elicit specific emotional responses.

Several prior works have focused on devising techniques to maintain the sense of immersion and presence when assessing the emotion-evoking effect within immersive environments [40,49]. However, these works heavily leaned on subjective feedback from participants, resulting in a lower ecological validity. In this work, we introduce a fully immersive and objective approach to assess the diverse effects of evoking emotions using immersive 360-degree videos, ensuring a high level of validity. This approach aims to provide a reliable tool that could enhance the quality and convenience of future emotion studies.

The objective of this study was to explore the potential use of attention-based Go/No-go tasks for evaluating the effect of emotion-evoking in an immersive environment. To achieve this, we utilized 360-degree videos to evoke emotions with different valence levels in an immersive environment. After that, we designed an experiment with Yellow Go/Blue No-go tasks. During these tasks, visual stimuli with different valences were presented to affect participants' attention. The reaction time (RT) in Go tasks and error rates in No-go tasks were analyzed using traditional and ex-Gaussian methods to examine attentional bias.

2. Related works

2.1. Theoretical basis for VR to bring immersion

Immersive media can enhance the sense of spatial presence, which derives from its technical characteristics, and can be explained by the VR environment's change to affordance [48]. Affordance refers to the part of the real-time environment that individuals pay attention to and interact with [14]. Previous studies illustrate that objects in a virtual environment also have affordance and are the starting point of sensory emotions in VR experiences [33]. According to affordance's principle, whether the object is in people's near space is an important factor affecting its existence, and those in near space are more likely to attract people's attention [2]. In this regard, compared to computer screens, VR can draw the stimulus to an individual's near-space, giving it affordance and making the information of stimulus fully perceived.

Furthermore, the embodied cognition theory explains how people make use of affordance to produce a sense of immersion. The concept in human cognition corresponding to affordance is named schema. In the VR scene, body schema has a projection function, which can map from original actions in the real world to perceptual actions in the virtual scene, thereby creating the illusion of autonomy and possession to enhance the sense of presence [31]. The latter is considered a prerequisite and necessary intermediary for emotions to occur in a virtual environment, and it is a match between human senses and virtual inputs and outputs [10]. Created by the illusion of autonomy and possession, the sense of presence created by VR is stronger and has a higher immersive level than it is when created by 2D videos [43].

2.2. Theoretical basis for immersive videos to evoke emotions

Unlike 2D videos, meta-awareness, including self-monitoring, is hard to occur in VR scenes [19]. Therefore, individuals will not pay attention to their current emotional state and bring it into consciousness so that they will be able to enter an immersive state [36]. The immersive state is a feeling of entirely devoting one's energy to a specific activity, whose most notable feature is that there is little extra self-thinking, accompanied by a high level of excitement and fulfillment [35]. When in a state of immersion, individuals do not necessarily have intensive emotional experiences because they are too invested in what they are doing to be aware of their emotional state at the time. However, when the immersion state fades, individuals will experience intense emotions [15]. This finding explains the advantage of immersive videos in evoking more intensive emotions.

In 2018, researchers from Stanford University provided a public database of immersive 360-degree videos, including values of valence and arousal, which were scored by a considerable number of participants [22]. The authors have published the public database through the Stanford Virtual Human Interaction Lab website, based on which our research is conducted.

2.3. Go/No-go paradigm for emotion measurement

The Go/No-go paradigm is a classic attention inhibition paradigm. In different trials of the Go/No-go experiment, participants will be presented with two kinds of stimuli. They are required to respond to one of them (Go) and not to respond to the other (No-go). The Go reaction's speed and the No-go reaction's correct rate are used as indicators of attention withdrawal [46]. According to hedonic contingency theory, in order to obtain positive emotions and their rewards, positive individuals tend to automatically choose more behaviors that can bring positive emotions than others [16,44,45]. In other words, people under positive emotions have an unconscious attentional bias toward positive stimuli [3,39,42]. The effect is also found between negative individuals and negative stimuli [1,26]. Therefore, attentional bias towards positive and negative emotions can be a measurement index of emotional valence and intensity: When individuals experience positive emotions, they encounter heightened difficulty in redirecting attention away from positive stimuli. Conversely, when negative emotions are evoked, individuals encounter increased difficulty in disengaging attention from negative stimuli.

Compared with commonly used laboratory emotion measurement methods, the Go/No-go paradigm shows its advantages in the following aspects: it is more objective than the self-report method, which will not be affected by defense mechanisms, rules of emotional expressions, and the influence of social approval effects [12,47]. Another advantage of the Go/No-go experiment is

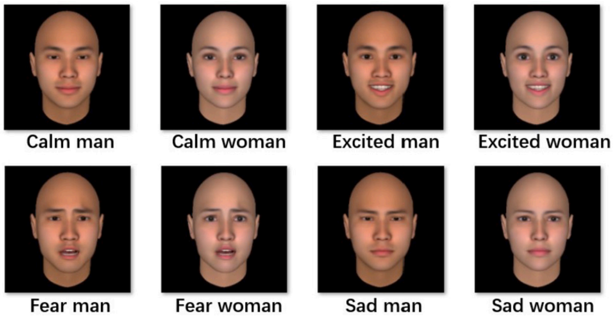

Fig. 1. Emotional faces generated by the FaceGen Modeller 3.4.

that it can save time and cost because it can be analyzed without physiological signals which are inconvenient to obtain, like electroencephalography (EEG) data.

2.4. Ex-Gaussian modeling for RT

Intra-individual variability in RT represents the within-person, trial-to-trial fluctuations in response latencies [18]. Traditional metrics used for assessing performance, such as mean and median RT, often fall short in capturing the intra-individual variability in RT [38]. To address this limitation, the utilization of Ex-Gaussian modeling offers a solution by effectively disentangling markedly slow responses from the faster responses present in the section of the RT distribution that adheres to a normal distribution [17]. RT data typically deviate from a normal (Gaussian) distribution, displaying a rapid rise in the distribution for shorter RTs and an elongated tail representing slower RTs. This distribution pattern aligns with the characteristics of the Ex-Gaussian distribution, which combines a Gaussian (on the left) and an exponential distribution (on the right) [27].

Application of the Ex-Gaussian model to RT data generates three parameters. The parameter τ estimates the proportion of very slow responses within the tail, describing the exponential component of the distribution. The parameters μ and σ denote the mean and standard deviation (SD) of the Gaussian component of the distribution. These three Ex-Gaussian parameters have been linked to distinct psychological processes. Specifically, the Gaussian components of the RT data, μ and σ, are used to mirror automatic, lower-level sensory-perceptual processes, encompassing information encoding and motor preparation/execution [13]. Conversely, the exponential tail, represented by τ, is presumed to capture lapses in attention resulting from deficiencies in top-down attentional control [13,37,50].

3. Experiment setup

3.1. Equipment and materials

- HTC Vive Pro Eye, a VR-HMD with a built-in eye tracker, the VR program used for Go/No-go tasks is built in Unity 2019.4.2f1 (64-bit) and loaded into the headset.
- Emotional face pictures made by FaceGen Modeller 3.4. Videos and pictures are divided into four categories according to the arousal-valence emotional model, as shown in Fig. 1.
- The 360-degree videos from Stanford Virtual Human Interaction Lab [22], the screenshot of the videos is shown in Fig. 2.
- The Simulator Sickness Questionnaire (SSQ) [20]. Participants need to score 16 symptoms on a four point scale (0-3). Participants who have a symptom scoring 3 are excluded in our study when analyzing results.

3.2. Go/No-go experiment in VR

The Go/No-go experiment program is developed using Unity and loaded into the VR-HMD. Once the participant is prepared to start the experiment, instructions for the experiment will be displayed on the HMD screen. The arrangement and sizes of the cubes and emotional faces are illustrated in Fig. 3 (a), (b), (c) and (d). The cubes are colored blue (#FFFF00) and yellow (#0000FF). When the participant completes reading the instruction, the program will start.

First, there will a training task 16 trials. The process is shown in Fig. 4. In each trial, a yellow or blue cube will randomly appear on either the left or right side of the HMD screen, accompanied by an emotional face picture in the center. During the time interval between consecutive trials, a black cross will appear at the center of the HMD screen to help the participant maintain focus.

Participants are required to respond according to the color of the cube. For the Go task, they should promptly look at the yellow square upon its appearance. For the No-go task, they must resist looking at the blue cube and instead maintain focus on the position of the emotional face picture.

Following the training task, there will be a formal task consisting of 96 trials. The process of each trial in formal task is the same as training task. Both blue and yellow cubes will appear 24 times on both the left and right sides, with their sequence being counterbalanced. In each trial, an emotional face picture will appear in the center of the screen to catch the participants' attention.

Fig. 2. Screenshot of the 360-degree videos used for emotion evoking.

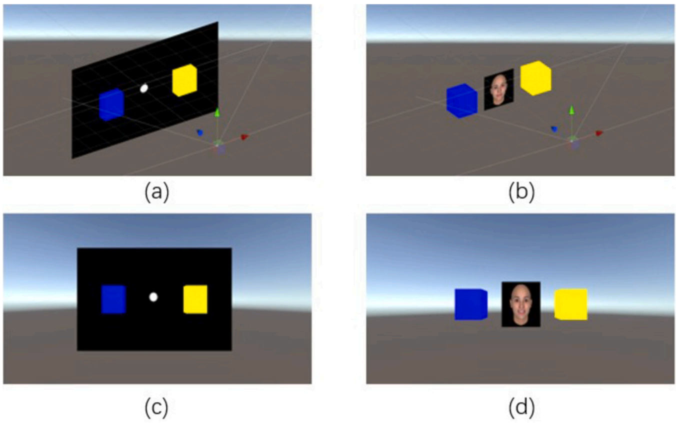

Fig. 3. (a) The position of the cubes in Unity editor. (b) The position of the emotional face in Unity editor. (c)The position of the cubes in VR-HMD. (b) The position of the emotional face in VR-HMD.

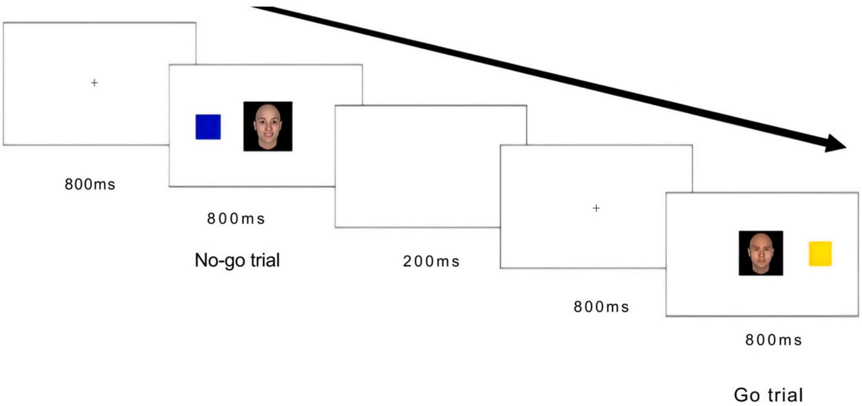

Fig. 4. The process of Go/No-go experiment.

Fig. 5. Schematic representation of the environment and equipment used by the participants to conduct the experiment.

There are eight types of emotional faces, and each type will be presented 12 times in the formal task, with their order being counterbalanced as well.

3.3. Procedure

28 college students were recruited through advertisements as participants. Each participant possessed a vision or corrected vision of 1.0 and did not have any mental disorders. None of the participants had prior experience using a VR-HMD. Before the experiment starts, an explanation of the experimental procedures was given to all participants, and eye-tracking calibration was performed on a user-by-user basis. Participants with severe intolerance to the VR-HMD were identified and excluded using the Simulator Sickness Questionnaire (SSQ). All participants voluntarily signed an informed consent form and confirmed that they understood the entire process. The Participants were randomly split into two groups based on the video's valence (positive/negative), with each group comprising 14 individuals. The experiment environment is illustrated in Fig. 5.

We used 360-degree videos to evoke four distinct types of emotions (High Valence High Arousal, High Valence Low Arousal, Low Valence High Arousal, and Low Valence Low Arousal) following Russell's model of emotions [35]. VR-HMD was used to display these videos. Before and after the emotion-evoking phase, a Go/No-go experiment was conducted to measure the participants' emotional states.

Emotional faces were used as stimuli to attract attention, as shown in Fig. 1. Specifically, eight emotional faces were categorized into positive and negative groups based on their valence level (high and low valence). The calm and excited faces represented positive stimuli (high valence), while the fear and sad faces represented negative stimuli (low valence). The emotional faces served as a within-subject variable.

The Go/No-go task aimed to measure participants' baseline emotional state and their emotional state after the emotion-evoking phase. The task consisted of 112 trials, comprising 16 practice trials and 96 formal experimental trials.

3.4. Data analysis

The reaction times (RTs) were analyzed using both traditional mean RT analysis and the ex-Gaussian approach. For the traditional mean RT analysis, the mean RTs of Go tasks were calculated for each condition. For the ex-Gaussian analysis, the "retimes" package in R statistical software was used to fit the models [28]. Ex-Gaussian parameters—μ, σ, and τ—were computed using bootstrapped re-sampling (1000 iterations) to ensure the robustness of the model.

4. Result

During data analysis, it became evident that the vast majority of participants experienced only 1-2 failed trials in the No-go tasks, representing an exceptionally low error rate ($< 2\%$) compared to the total trials. Consequently, we focused on the RT in the Go tasks as the principal measurement. To explore the impact of Video Valence (Positive and Negative) and the Consistency of

Table 1
Abstract of ANOVA for mean RT in Go tasks.

	F	Sig.	η_p^2
Consistency	1.368	0.253	0.050
Video Valence	0.730	0.401	0.027
Consistency × Video Valence	0.335	0.568	0.013

*: p<0.05.

Table 2
Abstract of ANOVA for ex-Gaussian parameters in Go tasks.

	μ			σ			τ		
	F	Sig.	η_p^2	F	Sig.	η_p^2	F	Sig.	η_p^2
Consistency	1.438	0.241	0.052	3.822	0.061	0.128	5.675	0.025*	0.179
Video Valence	0.341	0.564	0.013	0.005	0.947	0.000	0.314	0.580	0.012
Consistency × Video Valence	0.436	0.515	0.016	0.315	0.579	0.012	0.003	0.957	0.000

*: p<0.05.

video valance and emotional face (Consistent and Opposite) on the mean RTs and ex-Gaussian parameters in Go tasks, we used a two-way repeated-measures analysis of variance (ANOVA). Post-hoc test was conducted with Bonferroni adjustment. The threshold for significance was set at $p < 0.05$. Two-tailed paired t-tests adjusted with the Bonferroni correction were used to further examine significant main effects and interactions. Partial eta-squared and Cohen's d were calculated to estimate the effect sizes of factors in the ANOVA and paired t-tests, respectively.

4.1. Effects of video valance and emotional face on mean RT in go tasks

The results of ANOVA for RT in Go tasks are presented in Table 1. There was no significant main effect of Consistency ($F(1,26) = 1.368, p > 0.05, \eta_p^2 = 0.050$) or Video Valence ($F(1,26) = 0.730, p > 0.05, \eta_p^2 = 0.027$). No significant interaction is found between Consistency × Video Valence ($F(1,26) = 0.335, p > 0.05, \eta_p^2 = 0.013$).

4.2. Effects of video valance and emotional face on ex-Gaussian parameters in go tasks

The results of ANOVA for ex-Gaussian parameters are presented in Table 2. The ANOVA of mu (μ) showed no main effect of Consistency ($F(1,26) = 1.438, p > 0.05, \eta_p^2 = 0.052$) and Video Valance ($F(1,26) = 0.341, p > 0.05, \eta_p^2 = 0.013$). No interaction between Consistency × Video Valence is found ($F(1,26) = 0.436, p > 0.05, \eta_p^2 = 0.016$).

The ANOVA of sigma (σ) showed no main effect of Consistency ($F(1,26) = 3.822, p > 0.05, \eta_p^2 = 0.128$) and Video Valance ($F(1,26) = 0.005, p > 0.05, \eta_p^2 = 0.000$). No interaction between Consistency × Video Valence is found ($F(1,26) = 0.315, p > 0.05, \eta_p^2 = 0.012$).

The ANOVA of tau (τ) indicated a main effect of Consistency ($F(1,26) = 5.675, p < 0.05, \eta_p^2 = 0.179$), but no main effect of Video Valence ($F(1,26) = 0.314, p > 0.05, \eta_p^2 = 0.012$) and interaction between Consistency × Video Valence ($F(1,26) = 0.003, p > 0.05, \eta_p^2 = 0.000$). The main effect of Consistency showed a greater τ when the valence of video and emotional face are consistent ($t(27) = 2.427, p = 0.022, d = 0.459$).

5. Discussion

The presented results indicate that consistency of video valance and emotional face can significantly increase ex-Gaussian parameter τ. According to prior work, attentional or intentional processes can be captured by the exponential tail of the distribution (i.e., τ) [50]. Specifically, high values of τ index greater lapses in sustained attention [13,50]. In our experiment, greater τ indicates more trials of long RT for participants to withdraw attention from stimuli when it is consistent with participants' current emotional state, which aligns with existing literature [1,3,26,39,42]. This finding reveals the potential of attention-based approach for evaluating the emotion-evoking effects and the effectiveness of our Go/No-go experiment design.

There are several limitations for our experiment. First, we notice that a severe practice effect occurs in most participants, resulting in the average reaction time becoming shorter in the after-emotion-evoking Go/No-go task. Therefore, the relative value between groups will be discussed in the following part rather than the absolute value. Second, we have chosen 360-degree video from a public database as emotional stimuli, and the videos from the database are collected from Youtube. Therefore, the validity of 360-degree videos as evoking materials is limited due to the restriction of the website, which is also mentioned in the original paper [22]. This result is consistent with those obtained using the continuous measurement method embedded in the video in the previous studies [41].

Since the eye-tracking device we use is a built-in eye tracker inside the VR head-mounted display, we are not able to collect the eye-tracking data when the participants are watching 360-degree videos in 2D condition. While prior work shows that under the same valence level, emotions with low arousal have a shorter duration than emotions with high arousal [51]. Therefore, collecting and analyzing eye-tracking data during the video-watching process will be beneficial to understand the emotional states of participants.

The participants in our study were limited to university students, so the findings of this study cannot always be adapted to all populations due to the identity of the experimenter. In addition, due to the hardware limitations of the VR-HMD and the desktop computer, the frequency of eye movement data collection is constrained. As a result, we had to reduce the frequency of our experiment to ensure that all data were valid, which might lead to a decrease in data size, and some key frames may not be captured and analyzed.

6. Conclusion

Our study used Go/No-go paradigm to measure the emotion-evoking effect of 360-degree videos. Traditional and Ex-Gaussian methods are used to analyze the RT. We found that consistency of video valance and visual stimuli can significantly increase ex-Gaussian parameter τ, which represents the attentional bias towards the stimuli. Our findings suggest that Go/No-go paradigm is effective in evaluating effect of emotion-evoking in an immersive environment.

Ethical statement

The ethical approval number for this study is HR348-2023, approved by the ECNU University Committee on Human Research Protection.

CRediT authorship contribution statement

Feng Liu: Writing – review & editing, Writing – original draft, Supervision, Software, Project administration, Methodology, Formal analysis, Conceptualization. **Yihao Zhou:** Writing – original draft, Visualization, Software, Data curation. **Jingyi Hu:** Writing – original draft, Visualization, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The VR source code in this paper could be accessed from https://github.com/ECNU-Cross-Innovation-Lab/EEEinVR. The personal data cannot be disclosed due to ethical privacy requirements. Any questions can be directed to the corresponding author at: lsttoy@163.com.

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