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A Placebo Concert: The Placebo Effect for Visualization of Physiological Audience Data during Experience Recreation in Virtual Reality

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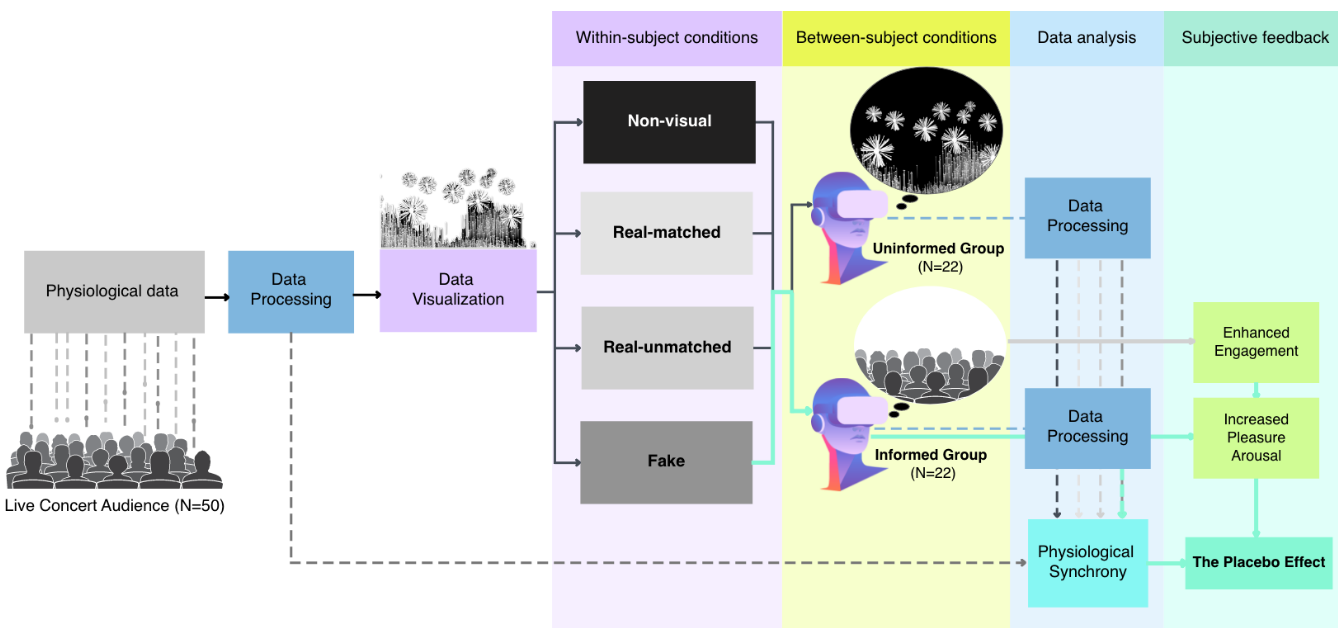

Figure 1: The workflow illustrating the process from data collection and processing to the user study, which includes four within-subject conditions: non-visual, real-matched, real-unmatched, and fake, and two between-subject conditions: uninformed and informed. The informed group showed increased engagement, with the fake condition in the informed group eliciting positive emotional responses, demonstrating the placebo effect.

Abstract

A core use case for Virtual Reality applications is recreating real-life scenarios for training or entertainment. Promoting physiological responses for users in VR that match those of real-life spectators can maximize engagement and contribute to more co-presence. Current research focuses on visualizations and measurements of physiological data to ensure experience accuracy. However, placebo effects are known to influence performance and self-perception in HCI studies, creating a need to investigate the effect of visualizing different types of data (real, unmatched, and fake) on user perception during event recreation in VR. We investigate these conditions through a balanced between-groups study (n=44) of uninformed and informed participants. The informed group was provided with the information that the data visualizations represented previously recorded human physiological data. Our findings reveal a placebo effect, where the informed group demonstrated enhanced engagement and co-presence. Additionally, the fake data condition in the informed group evoked a positive emotional response.

CCS Concepts

• **Human-centered computing** → **User studies**; **Virtual reality**; *Empirical studies in HCI*.

Keywords

Virtual Reality, Placebo Effect, Concert, Electrodermal Activity, Blood Volume Pulse

ACM Reference Format:

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1 Introduction

Since its initial developments, one of the goals of Virtual Reality (VR) is to allow users to easily step into a wide variety of experiences [5, 62]. LaValle [62] describes VR as inducing targeted behaviors, as designed by the creator, in an organism, usually but not necessarily a human, by using artificial sensory stimulation, involving one or more senses, while the organism has little or no awareness of the interference, which can lead to the feeling of being *present* in a different world. Effectively, when well executed, VR can invoke for the user the sense of being teleported into a different reality [27, 58, 82, 95].

Depending on their purpose and application, virtual worlds can be digital twins of a real place, as well as fictional or abstract [14, 20, 44, 100, 109]. However, previous research has highlighted that to support the sense of presence, VR systems should obey rules of internal consistency and logic, which add to the plausibility of the experiences and help to shape the perception of the user [41, 88, 105].

The recreation of real-life environments and behaviors is essential if the user is expected to react in the same way they would in real life. Especially for training scenarios this helps to ensure that the learned skills, behaviours and reactions in VR can be transposed for real world application [6]. The replications therefore allow for a safe training environment where the user can acquire new skills without getting in harms way [76]. The advantage of a simulation for the designers is that they know how the replications are supposed to look and behave like. However, the implementation itself remains challenging as even small details might destroy the illusion of the simulation [91]. Meanwhile, more abstract visuals can help to avoid the uncanny valley [92].

Burdea & Coiffet [11] points to VR being articulated around three Is: "Immersion", "Interaction" and "Imagination". Abstract VR experiences go beyond the replication of reality by offering abstract visualization or alterations of the users senses, deviating from the norm of how the virtual world is supposed to look like to offer an "immersive" experience. Ranging from simplified haptics, pseudo-haptic illusions, or abstract virtual avatars [45, 60, 69]. Simple visualizations or actuation are equally feasible to induce the sense of presence in a virtual world. Further, designers can use these simplifications to not only enable but also enhance the experience by user being letting the user focus on the essential elements of the experience.

One part an recreation in VR is the recording of the original scene that is to be replicated. Recent advancements in wearable biosensors and digital media technologies have enabled artists and researchers to integrate the human sensory and emotional experiences of audiences into performance environments. In live performance settings, spontaneous emotional experiences of the audience can be transformed into data [13], affective pictograms [43], and virtual avatar icons [10, 113], among other abstract forms. Since the display of emotions can evoke reciprocal emotional responses [52], some researchers have developed "affective loop experiences" centered around participants' physiological feedback [42].

Building on earlier research that incorporated physiological feedback into integrated loops [26, 53, 110], this study further extends the application of physiological signals in group interactions. We visualize live audience data in an abstract form and integrate it into virtual reality re-creation scenarios, bridging the gaps of time and space, and fostering connections between VR users and audience collectives from the past.

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However, Kosch et al. demonstrate that a user can be primed and influenced about technology in the HCI context [59], therefore creating a placebo effect which results in a change of perceived performance [7], as well as perceived trustworthiness, empathy, and effectiveness of a system [80]. Therefore, by conducting a user study (n = 44), we investigated the existence of a placebo effect when using visualizations of physiological data. We compared real audience data, real audience data from different performances, and randomized fake data on the user in a concert recreation in VR. By dividing the participants into two groups, informed and uninformed). The informed group was provided with information that the data visualizations represented human physiological data recorded during the concert performance. We could verify the existence of a placebo effect for physiological data visualization.

Contribution Statement:

Our contribution is threefold: (1) a mixed-method user study (n = 44) where participants experienced a concert recreation in VR that uses an abstract physiological data visualization; (2) the discussion of the influence of the visualization of physiological data and the placebo effect thereof, regarding user engagement, presence, co-presence, and emotional responses; and lastly, (3) a data visualization VR setup, a dataset containing field data and laboratory setup data.

2 Related Work

2.1 VR for event recreations

Virtual reality has gained significant attention from all corners of the entertainment industry, from sport [54], tourism [63], cinema [74], theatre [38], and music [116]. Recreations of sporting events or artistic performances in virtual reality can effectively support the ability to experience a particular event that an individual was not able to attend in person due to a variety of reasons, thus potentially increasing accessibility and democratizing viewing experiences [4, 19, 54, 71, 117].

To understand the difference in the experiences of the audience when witnessing an open-air musical conference in different formats Scorolli et al. carried out an experiment comparing the impact on esthetic experience and social presence across four different conditions: live event, video stream, VR with the low-powered device, and VR with the high-powered device [93]. Results from the study highlight that while the live event was overall rated as the most aesthetically beautiful, differences observed in comparison to viewing experiences with the VR with high-powered devices were not significant [93]. Moreover, the VR with a high-powered device was more successful than live experiences in promoting interest in watching future performances of the same genre, compared to all other conditions [93]. Unfortunately, data collected by the authors about social presence did not pass internal consistency tests and could not be statistically analyzed.

To enhance both aesthetic appreciation and a sense of social presence in recreated VR events, researchers have adopted multiple strategies focused on increasing the realism of the experience [79]. Examples included allowing for the selection of multiple points of view [55], supporting active navigation [65], incorporating visualizations based on the user's physiological signal [46], and introducing realistic avatars of other spectators [4, 98]. Many of these approaches require the use of high quality visual content from the actual event, or the careful reconstruction of realistic digital avatars, both of which can necessitate significant manual tinkering and/or substantial computational power for adequate rendering [77]. Hoppe further argues that striving for mimicry could also hinder the ability to explore how VR could create new experiences that are different, and possibly better, than the original [44].

The problem with high fidelity reproductions is also that small glitches or inaccuracies can run the risk of disrupting the sense of presence by failing the test of plausibility, defined by Slater et al. as the perception that the depicted event has actually occurred [97]. An example of this is the description of digitalized avatars representing members of the audience at the VR recreated concerts as disturbing, and actively detracting from the enjoyment of the experience, and taking the attention focus of the viewer away from the stage [4, 98]. A better way to promote enjoyment and foster a sense of presence without requiring the use of such a complex and fragile hyper-realistic illusions, would be to explore ways to create a more abstract way to represent surrounding audience in more suggestive ways which create a more subtle illusion of a shared experience. In the next section, we examine the modalities in which physiological data has been used with this goal in the context of live music events to investigate the potential of such an approach in VR.

2.2 Capturing and Measuring Live Performances

There is a body of work exploring engagement in live performances [29]. What does it mean to be live? Researchers and artists explored topics from interacting with the body movements of dancers to the use of bio data [17, 37, 50, 61, 81, 114]. There are even live theater performances measuring the interpersonal synchrony between actors and audience [104]. Others are streaming live audience physiological data in real-time and change visualizations, sound, and lighting on the stage [34, 48, 103]. The ethics of biometric capture in immersive artistic performances are also discussed [99]. Some of those works are focusing on the link between the performer and the audience at the moment, trying to enhance engagement or liveness. There are little works who try to reconstruct liveness or recreate the feeling of a live event using physiological data.

In recent years, advancements in wearable biosensors and digital media have allowed researchers to incorporate audience emotional experiences into live performances. While much research has focused on sharing physiological data during performances to evoke emotional responses, our project uniquely aims to capture these signals and reproduce them in a different location and time. By using Electrodermal Activity (EDA) and Blood Volume Pulse (BVP) data, we seek to bridge the gap between live and virtual environments, creating a VR experience that captures the emotional atmosphere of a classical concert, an area not yet explored in existing studies.

2.3 Investigating Physiological Synchrony in HCI

The concept of physiological synchrony refers to the phenomenon by which physiological parameters linked with the action of the autonomic nervous system tend to align between individuals during shared activities, higher degrees of physiological synchrony have been associated with stronger emotional bonds and emotional resonance [1, 16, 30, 49, 68, 75, 86, 101, 102]. Physiological synchrony and its implications have been the subject of extensive study in a variety of fields encompassing, neuroscience, psychology, sport science, cognitive and behavioural science, medicine, and robotics [68, 72, 102, 106, 107]. Several HCI researchers have investigated how physiological synchrony can be assessed utilizing different wearable and embedded sensors including smart watches [23, 36], fitness trackers and wristbands with similar characteristics [3, 34, 51], EEG and respiratory sensors [72], eye tracking devices [30], and cameras [31]. Moreover, extensive interest in HCI research has also been dedicated to understanding how physiological synchrony can be enhanced by providing biofeedback stimuli using multimodal channels between dyads as well as larger groups [33, 35, 39, 51, 64, 66]. The extensive literature review by Feijt et al. shows that sharing reciprocal biofeedback information improves social interactions and increases the sense of intimacy between individuals [28]. Moreover, the review by Moge et al. illustrates how asymmetrical social biofeedback, where the physiological data of one party are transmitted to the other in a non-reciprocal fashion, can foster both affective empathy and true social connectedness [73]. Furthermore, such mechanisms are effective not just in synchronous and co-located scenarios, but also in asynchronous and distributed ones. On the other hand, Howell et al. describe how when individuals observe visual displays communicating changes in other people's physiological state, their interpretation of the meaning is affected by the ambiguity of observation (linked to the purposeful imprecision in the design of the visualization), and ambiguity of meaning (due to fact the different emotions can result in similar physiological changes) [47]. The design and deployment of a mobile application providing purposefully ambiguous representation of skin conductance by Sanches et al. can lead to the emergence of proto-practices, with people tentatively modifying their behaviours to achieve a desired goal [87]. Overall, existing HCI research has experimented with different forms of biofeedback strategies to promote physiological synchrony, and explored the potential of ambiguity on self-representation to stimulate behaviour change. However, there is still limited work that looks at how ambiguity in the representation of physiological data could be exploited to promote increased positive responses and heightened synchrony between individuals, suggesting the emergence of a placebo effect.

2.4 Placebo in HCI

The placebo effect in medicine describes patients receiving real benefits from a treatment without any active agent, therefore, creating the illusion that a treatment changes the patients' response. Kosch et al. demonstrate a placebo effect in adaptive interfaces and argue that the placebo effect in HCI is largely unexplored and should be considered to be tested for in HCI studies that aim at altering user perception, performance or behavior [59]. Similarly, users' perception of privacy protection tools may be more influenced by how they are described rather than their actual functionality. Research has shown that when browser tracking protection extensions are framed as providing functional or placebo protection, users feel more secure, even when no actual protection is applied [111]. The heightened expectations towards technologies such as AI need to be managed to avoid a placebo or nocebo effect [57]. Whereas successfully priming the user with a study narrative results in a change of perceived performance while not affecting objective performance data [7], as well as the narrative being able to increase perceived trustworthiness, empathy, and effectiveness of a system [80].

Play-testing during game development showed that how they are experiencing and perceiving the game is shaped by their expectation and prior knowledge. Untrue given instructions about the game and its improvements such as adaptive AI, can change the player's perception and result in a higher level of perceived immersion.

The placebo effect and the inclusion of placebo conditions in user studies are not widely established in HCI. While physiological data visualization has often been used to alter user perception or improve performance, these studies typically lack placebo conditions. As a result, the potential influence of placebo effects in the context of physiological data visualization remains unexplored in HCI research.

3 User Study

The study investigated the existence of a placebo effect in the visualization of physiological data. It was conducted in the context of a VR concert recreation to explore user perceptions of different data visualizations.

3.1 Concept

Building upon the findings from a prior experiment *anonymized publication provided as supplementary material in precision conference*, which demonstrated that fully abstract symbolic scenes positively influence emotional experiences, this study further investigates how data types and priming information affect user experience in abstract VR recreation. The goal of this research is to investigate the decisive factors that influence user engagement when applying physiological data visualization to recreate a collective atmosphere in VR. Specifically, this study aims to determine whether real human physiological data or randomly generated fictional data is more effective in enhancing user engagement and co-presence. Additionally, the research seeks to explore whether VR users can distinguish between physiological data that matches the emotional context of the recreated scene and data that does not, and how these differences impact their overall experience and emotional states.

In this study, a modular data visualization system was built to capture, process, and visualize physiological data from individual audience, and subsequently integrate these data into a collective representation. The system workflow consists of four main stages:

On-Site Data Collection: During this initial stage, physiological data were recorded for 50 audience members (female: 25, male: 20, unspecified: 5) aged between 7 and 73 years (mean age = 33.48, standard deviation = 14.65) during a classical concert. The device

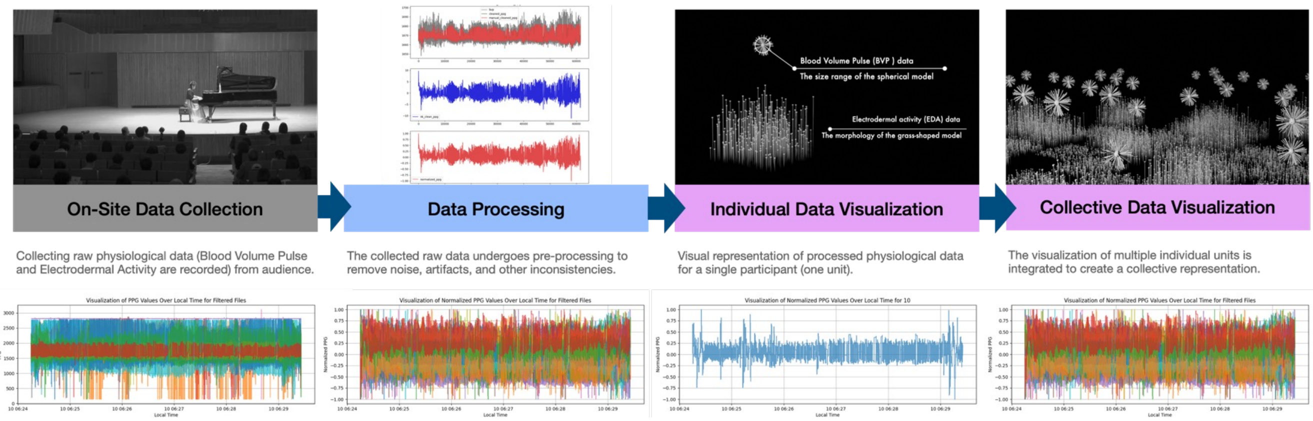


Figure 2: Process of Collective Data Visualization: This process involves on-site data collection of physiological signals, data processing, individual data visualization, and the integration of multiple units for collective data visualization. The system enables the transformation of multiple individual physiological datasets into dynamic 3D visualizations, supporting rapid visualization generation for VR environments.

used for Blood Volume Pulse (BVP) and Electrodermal Activity (EDA) data collection was a wearable wristband, with sensors placed on participants' fingers to minimize any potential hesitation or discomfort. For recording the data of audience members, we used a commonly employed physiological sensing platform [39, 103]. All audience members and performers provided informed consent, and the experimental setup was approved by the ethics committee of Keio University.

Data Processing: The collected raw data underwent pre-processing to enhance quality by removing noise and artifacts. This stage involved applying filtering techniques [108], normalization procedures, and segmentation to prepare the data for visualization. Excluding instances with unrecorded data due to technical malfunctions, we collected 47 EDA and 41 BVP recordings from 50 audience members at the on-site live concert. EDA data that did not meet Boucsein's definition of EDA responses [8, 40] were excluded after integration with the initial model and inspection. By ruling out incomplete or noisy data records, we retained 40 EDA and 36 BVP recordings from the concert audience.

Individual Data Visualization (One Unit): At this stage, the pre-processed data from the audience is visualized on an individual basis, with the objective of representing a single person's physiological responses through visual tools, such as 3D models. The purpose of these visualizations is to provide a representation of individual physiological data.

In this study, a 5-minute 11-second solo piano performance video was edited, and the data from the same period was transformed into 3D visualizations. We developed a prototype in Blender that converts physiological data into 3D models, where each unit of the model is designed to represent the physiological state of an individual audience member. This approach integrates bio-art principles that align with the musical atmosphere of the concert. The organic forms, inspired by characteristics of living organisms, are closely associated with physiological attributes, suggesting that these data-driven transformations are inherently imbued with emotional qualities [112].

For each unit, individual EDA and BVP data are represented by distinct 3D models. The BVP data is represented by the scale parameter of a dandelion-like spherical model that simulates heartbeats (recent evidence indicates that the perception of expressive biological signals, such as heartbeats, can enhance emotional understanding and foster interpersonal connections). Meanwhile, the EDA data is depicted by a patch of grass-like models, with the height parameter of the rising blades from the ground representing the EDA levels.

Collective Data Visualization (Integration of Multiple Units): The final stage involves integrating multiple individual data visualizations into a collective representation. This integration allows for the examination of group-level patterns and interactions, enhancing insights into collective physiological responses.

The modular approach of this data visualization system enables scalability from single-unit visualizations to complex, multi-unit integrations, supporting a wide range of applications in visualizing both individual and collective physiological data.

Through this approach, we have established a fundamental framework that can transform collective/multi-participant physiological data into dynamic 3D visualizations. This framework allows for the rapid generation of visuals by importing different types of data and can be applied to the construction of VR environments. This lays the foundation for subsequent experiments.

3.2 Conditions

The experiment utilized a mixed two-level design with both between-groups and within-subject conditions. Four within-subject conditions compare the visualization of four different data sets. The two groups are used to investigate the effect of knowledge of the purpose of the visualizations, as suggested by Kosch et al. Each participant experienced all four data type conditions in a counterbalanced order to control for order effects. The entire experiment lasted approximately 90 minutes. The experimental setup was approved by the ethics committee of Keio University.

The four within-subject conditions, which test the impact of different data sets, are as follows:

- **Non-visual (Non-Vis):** Participants were only exposed to auditory, with no data set being visualized.
- **Real-matched (Matched):** Participants viewed data visualization that accurately derived from real physiological data collected from live audience during the actual performance. The data visualization matches the performance context, reflecting the physiological responses of the audience to the audio and other elements of the performance, creating a contextually relevant experience.
- **Real-unmatched (Unmatched):** Participants viewed data visualizations derived from real physiological data that did not correspond to the actual performance being recreated. Although the data were authentic, they did not match the performance context, resulting in visualizations that were disconnected from the audio and other elements of the scene.
- **Fake (Fake):** Participants viewed data visualizations generated randomly, not based on any real human data.The fake data generation process involved using Python and the `numpy` library to create random values within a specified range. First, the range was defined to ensure all generated values adhered to the specified boundaries. Using `numpy.random.uniform()`, random values were generated, ensuring uniform distribution. These random values were used to drive parameters of the 3D model, such as scale or height, resulting in dynamic transformations for each frame of the animation. However, the generated data set does not match any music features (e.g., rhythm) or audience physiological data and was solely used to provide random visual effects.

To test for a potential effect of being aware of the purpose of the visualization, the participants were divided into two groups:

- **Group 1 - Uninformed ($_U$):** Participants were not given any prior information regarding the visualizations.
- **Group 2 - Informed ($_I$):** Participants were informed that the visual effects represented physiological data of audience members recorded during the concert they were experiencing. However, no additional information was given about the control conditions where data from a different performance (Unmachted), and randomized data (Fake) were used.

To further investigate the impact of knowledge about the data visualizations, each of the four data conditions—non-visual (Non-Vis), real-matched (Matched), real-unmatched (Unmatched), and fake (Fake)—was examined under both informed and uninformed settings: Non-Vis$_U$, Non-Vis$_I$, Matched$_U$, Matched$_I$, Unmatched$_U$, Unmatched$_I$, Fake$_U$, and Fake$_I$, where the subscript indicates whether participants were in the uninformed or informed group.

3.3 Apparatus

The VR environment was created with Unity3D and ran on a PC with Windows 11, Intel Core i9-14900HX, NVIDIA GeForce RTX 4090, and 32GB RAM. The VR scenes were presented on a Meta Quest Pro, a VR headset with a Snapdragon XR2+ processor, 12 GB of RAM, and dual LCD displays at 1800 x 1920 pixels per eye with a 96-degree FOV. The device supports a 90 Hz refresh rate and includes built-in headphones for spatial audio. Participants wore physiological data acquisition devices on their non-dominant hands during the experiment, employing a commonly used physiological sensing platform [34, 39, 48, 103]. The devices utilize ESP32 modules and stream recorded data via WiFi. EDA, representing changes in skin conductance, is measured using a Wheatstone bridge, an instrumentation amplifier, and a 16-bit ADC within a ±2V range, with basic low-pass RC filters applied to both. The EDA sampling rate is 10 Hz, with a resolution of 12 bits. The participants were seated in a 360-degree rotating chair during the VR experience.

3.4 Participants

A total of 44 participants (n = 44) were recruited for this study, with a mean age of 27.8 years (SD = 3.47) and an age range of 21-35 years (Female: 28, Male: 15, Unknown: 1). The experiment utilized a mixed design with both between-groups and within-subject conditions. The participants were randomly divided between the two groups: informed (n = 22) and uninformed (n = 22). No participant had to be excluded from the study. However, the recorded data of some participants had to be excluded due to incomplete data capture, or high levels of noise and artifacts that could not be adequately filtered out. More detailed information on this is given in the analysis section. To compensate the participants for their time, each participant received a 10.34 USD Amazon gift card.

3.5 Procedure

After welcoming the participants, they were introduced to the user study procedure. Afterwards, they were led through the following steps (see Figure 3):

(1) Informed Consent: Participants were informed about the experiment procedure and signed the consent form and data protection policy. The uninformed group received no information about the visualizations, while the informed group watched a video explaining the concert recreation and data visualizations, with further clarifications provided as needed.
(2) Personal Data Collection: Participants provided basic information (age, gender, concert experience). The wrist-worn data acquisition device was placed on their non-dominant hand, and they were advised to minimize hand movements to ensure accurate data collection. Participants wore the device throughout the experiment, with a 5-minute baseline recording conducted before the virtual experience.
(3) Experiencing Data visualization Condition: The experimenter selected the appropriate trial category for the participants and provided them with the Meta Quest Pro virtual reality HMD. The VR experience began after the participant put on the HMD, adjusted the fit and strap for comfort, and optimized the lens distance, interpupillary distance, and focal distance to ensure a clear view. The experience lasted 5 minutes and 11 seconds, and participants could interact with the environment through rotation and small movements based on the HMD's physical position while seated in a 360-degree rotating chair.
(4) Filling the Questionnaire: When the participant completed an experience with a data type condition, he or she filled out

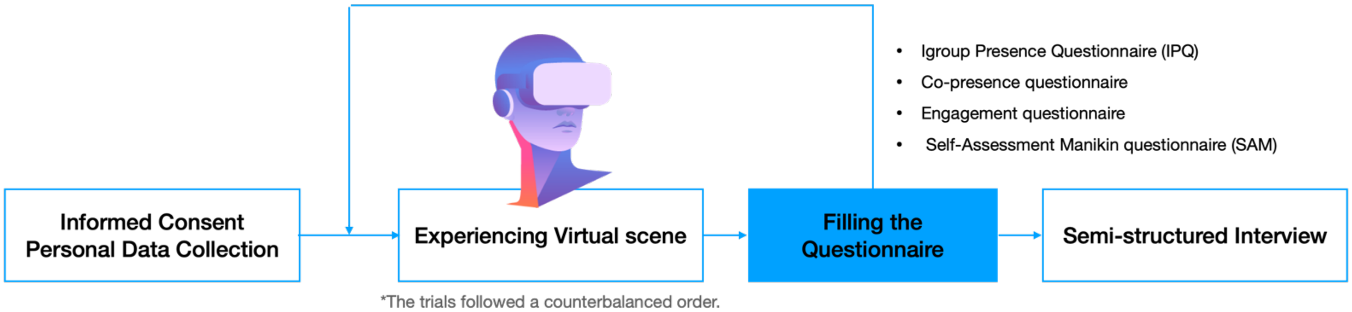


Figure 3: The user study (n = 44) was conducted as a balanced between-groups design of uninformed and informed participants regarding the purpose of visualizations and four counter-balanced within-subject conditions of different data visualization.

the SAM (Self-Assessment Manikin) questionnaire, engagement questionnaire, co-presence questionnaire, and Igroup Presence questionnaire.

(5) Trials with Different Conditions: The experiment was then repeated for the remaining three conditions. Participants repeated the steps (3) to (5) under each condition.
(6) A semi-structured interview was conducted with each participant, focusing on four main areas: their overall perceptions of the VR experience, preferences among the four data type conditions, insights into the visualizations, and emotional changes across the four conditions.
(7) After the study was completed, the participants received their compensation. We thanked them for taking part in the study and answered any questions they had.

3.6 Measures and Analysis

We collected participants' demographic information and their previous experience with attending concerts. During the experiment, after each condition, participants were asked to complete a set of questionnaires: We employed the 9-point Self-Assessment Manikin (SAM) scale to measure participants' emotional responses during the VR experience under different conditions [9]. To evaluate the sense of presence within the virtual environment, we employed the 7-point Igroup Presence Questionnaire (IPQ) [89, 90]. This questionnaire assesses multiple dimensions of presence, including spatial presence, involvement, and experienced realism, to determine how immersed participants felt in the VR environment.

Additionally, to examine differences in the sense of co-presence across various conditions, we adopted the Co-Presence Questionnaire proposed by Bailenson et al., which measures the degree to which participants feel they are "together" with others in the virtual environment [2]. As live performances are inherently social events that involve interaction and shared experiences among audience members, capturing co-presence helps determine whether the VR experience successfully replicates these essential social dynamics.

We measure engagement in the VR recreation because the cognitive analysis of a performance is a collective phenomenon closely tied to social communication and interaction, which is central to enhancing a spectator's understanding and enjoyment of a performance. McCarthy et al. explain that collective engagement in the arts provides significant value by allowing individuals to express private feelings together, creating a sense of connection and reducing feelings of isolation [70]. By assessing engagement in VR, we aim to understand if these essential elements of social experience are effectively recreated in a virtual environment.

We designed a 7-point scale to measure engagement in live performances based on the framework by Radbourne et al. [85]. The scale focuses on three key aspects of audience engagement: (1) communication between performers and the audience, (2) communication between audience members, and (3) the individual audience member's sense of belonging to a collective whole.

Further, after completing all conditions, the experimenter conducted a semi-structured interview with both informed and uninformed participants, focusing on four main areas: their overall perceptions of the VR experience, preferences among the four data type conditions, insights into the visualizations, and emotional changes across the four conditions.

For the uninformed group, the questions centered on identifying which part of the experience they preferred the most and why, their interpretation of the visuals, what they thought the visuals represented, and their emotional responses during the VR experience.

For the informed group, the questions aimed to explore their preferences among the four conditions, their understanding of the visuals after viewing the explanatory video, their thoughts on the information conveyed, the effectiveness of the video in helping them understand the virtual scenes, and their emotional responses during the experience.

A mixed-design ANOVA was conducted to examine the effects of data visualization conditions—non-visual (Non-Vis), real-matched (Matched), real-unmatched (Unmatched), and fake (Fake)—under both informed and uninformed settings on user engagement, co-presence, presence, and emotions. The within-subject factor was the data visualization condition, and the between-subject factor was the participant group (uninformed vs. informed). The conditions were analyzed as Non-Vis$_U$, Non-Vis$_I$, Matched$_U$, Matched$_I$, Unmatched$_U$, Unmatched$_I$, Fake$_U$, and Fake$_I$, where the subscript indicates whether participants were in the uninformed (U) or informed (I) group.

4 Results

4.1 Questionnaires

In the following, we report the results for engagement, co-presence, presence, and emotions.

4.1.1 Engagement. The analysis revealed a significant main effect of the data visualization condition on engagement, $F(3, 103) = 18.16$, $p < .001$, $\eta^2 = 0.302$. Post-hoc comparisons indicated that engagement was significantly higher in the Fake_{U} condition compared to the $\text{Non-Vis}_{\text{U}}$ condition ($p < .05$) and the $\text{Matched}_{\text{U}}$ condition ($p < .01$). Additionally, post-hoc comparisons showed that engagement was significantly lower in the $\text{Non-Vis}_{\text{I}}$ condition compared to the $\text{Matched}_{\text{I}}$ condition ($p < .001$), the $\text{Unmatched}_{\text{I}}$ condition ($p < .001$), and the Fake_{I} condition ($p < .001$), as shown in Figure 4.

A significant interaction effect was found between the data visualization condition and group information, $F(3, 103) = 5.23$, $p < .01$, $\eta^2 = 0.111$, indicating that the effect of the data visualization condition on engagement differed depending on whether participants were informed or uninformed.

There was also a significant main effect of group information (informed vs. uninformed) on engagement, $F(1, 42) = 4.61$, $p < .05$, $\eta^2 = 0.099$. Participants in the informed group (I) reported higher engagement levels compared to those in the uninformed group (U).

4.1.2 Co-Presence. The mixed-design ANOVA on co-presence showed a significant main effect of the data visualization condition, $F(3, 113) = 17.94$, $p < .001$, $\eta^2 = 0.299$, indicating that different types of visualizations influenced the sense of co-presence among participants. There was also a significant interaction between data visualization and group information (informed vs. uninformed), $F(3, 113) = 7.49$, $p < .001$, $\eta^2 = 0.151$, but no significant main effect of group information alone, $F(1, 42) = 3.44$, $p = .071$, $\eta^2 = 0.076$.

To further understand these effects, we conducted an additional analysis by removing the non-visual condition. After excluding this condition, the results showed no significant main effect of data visualization type, $F(2, 84) = 0.88$, $p = 0.42$, $\eta^2 = 0.020$, and no significant interaction between data visualization and group information, $F(2, 84) = 0.11$, $p = 0.90$, $\eta^2 = 0.003$. However, there was a significant main effect of group information, $F(1, 42) = 7.66$, $p = 0.008$, $\eta^2 = 0.154$, indicating that participants in the informed group reported a higher sense of co-presence compared to the uninformed group.

These results suggest that including the non-visual condition influenced the overall findings, highlighting the role of data visualization in affecting co-presence. When the non-visual condition was removed, the group information (informed vs. uninformed) became a more prominent factor in determining co-presence, with informed participants experiencing a higher sense of co-presence overall.

4.1.3 Igroup Presence. The analysis revealed a significant main effect of data visualization on presence, $F(3, 107) = 36.87$, $p < .001$, $\eta^2 = 0.467$, indicating that different visualization conditions affected the perceived sense of presence among participants. The interaction between data visualization and group information (informed vs. uninformed) was also significant, $F(3, 107) = 3.80$, $p = 0.017$, $\eta^2 = 0.083$, suggesting that the impact of the visualization conditions on presence differed depending on whether participants were informed or uninformed. However, there was no significant main effect of group information alone, $F(1, 42) = 0.048$, $p = 0.83$, $\eta^2 = 0.001$.

Further analysis showed that presence in the non-visual condition (Non-Vis) was significantly lower than in the visualization conditions. While high-fidelity visual characteristics such as resolution (immersion) are not necessary to achieve high presence [96], the inclusion of additional modalities tends to achieve a higher level of presence in the user. This aligns with general expectations about the role of visuals in VR. Excluding Non-Vis, there were no significant differences in presence across the other data visualization conditions or between informed and uninformed groups, suggesting similar performance among the visualization conditions.

4.1.4 SAM Scale. The mixed-design ANOVA was conducted to analyze the effects of data visualization conditions on three dimensions of the Self-Assessment Manikin (SAM) scale:

Pleasure: The results revealed a significant main effect of data visualization condition on Pleasure, $F(2, 88) = 3.46$, $p = 0.034$, $\eta^2 = 0.076$, indicating that the type of data visualization influenced participants' pleasure levels. Post-hoc comparisons showed that the $\text{Unmatched}_{\text{U}}$ resulted in significantly higher pleasure than the $\text{Matched}_{\text{U}}$ ($p < .05$). Additionally, the Fake_{I} showed significantly higher pleasure than the $\text{Non-Vis}_{\text{I}}$ ($p < .01$), $\text{Matched}_{\text{I}}$ ($p < .05$), and $\text{Unmatched}_{\text{I}}$ ($p < .05$), as shown in Figure 5(a). There was no significant interaction between data visualization and group information (informed vs. uninformed), $F(2, 88) = 1.61$, $p = 0.204$, $\eta^2 = 0.036$, and no significant main effect of group information alone, $F(1, 42) = 0.018$, $p = 0.893$, $\eta^2 = 0.000$.

Arousal: For Arousal, the analysis showed a significant main effect of data visualization condition, $F(3, 115) = 8.30$, $p < .001$, $\eta^2 = 0.165$, suggesting that different visualization conditions affected participants' arousal levels. Post-hoc comparisons indicated that the Fake_{I} evoked significantly higher arousal than the $\text{Non-Vis}_{\text{I}}$ ($p < .001$), $\text{Matched}_{\text{I}}$ ($p < .001$), and $\text{Unmatched}_{\text{I}}$ ($p < .05$), as shown in Figure 5(b). There was no significant interaction between data visualization and group information, $F(3, 115) = 0.36$, $p = 0.761$, $\eta^2 = 0.009$, and no significant main effect of group information, $F(1, 42) = 1.60$, $p = 0.213$, $\eta^2 = 0.037$.

Control: The results for Control showed no significant main effect of data visualization condition, $F(3, 123) = 1.69$, $p = 0.174$, $\eta^2 = 0.039$. Additionally, there was no significant interaction between data visualization and group information, $F(3, 123) = 0.267$, $p = 0.844$, $\eta^2 = 0.006$, and no significant main effect of group information, $F(1, 42) = 0.015$, $p = 0.903$, $\eta^2 = 0.000$.

4.2 Physiological Synchrony of EDA

Besides subjective feedback from audience members, we explored the physiological data collected to calculate the physiological synchrony (PS) between VR participants and the live audience. PS occurs when the physiological activity between two or more individuals becomes associated or interdependent, making it a feasible metric to quantify the experience of physiological connectedness [78].

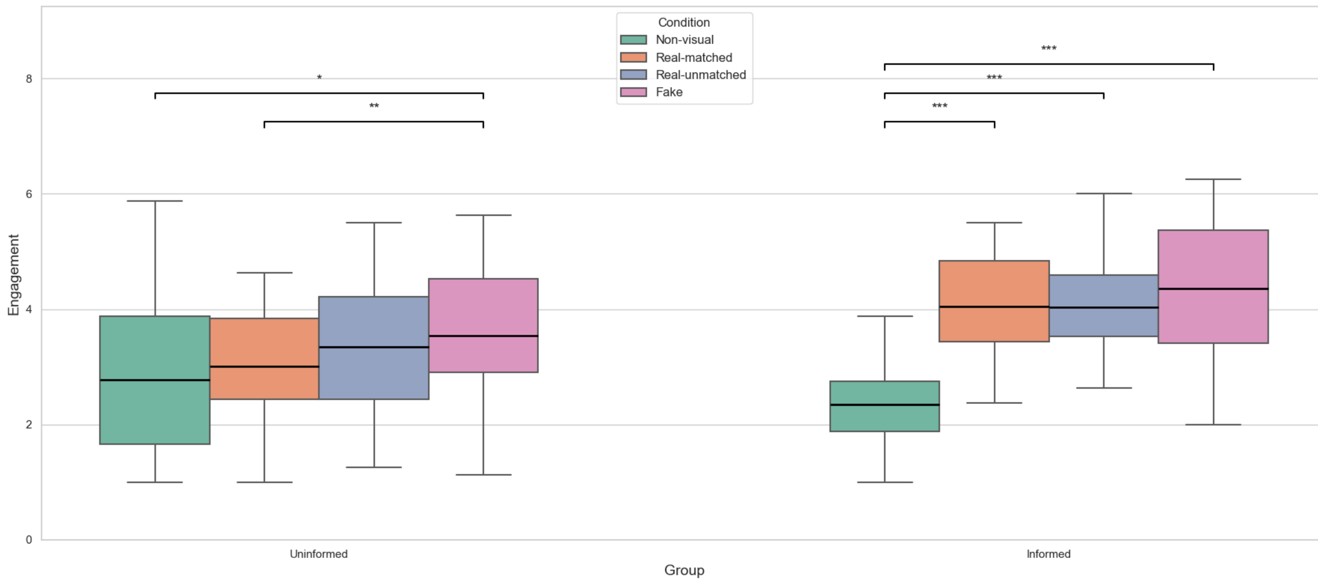


Figure 4: Engagement across data visualization conditions. Fake_U is significantly higher than Non-Vis_U and Matched_U, while Non-Vis_I is significantly lower than Matched_I, $\text{Unmatched}_\text{I}$, and Fake_I.

We focused on Electrodermal Activity (EDA) data, as it captures both rapid (phasic) and sustained (tonic) changes in emotional arousal. In contrast, the complexity of analyzing Blood Volume Pulse (BVP) features, combined with its lower temporal resolution, makes BVP less effective for assessing physiological synchrony in the dynamic, brief settings of this study.

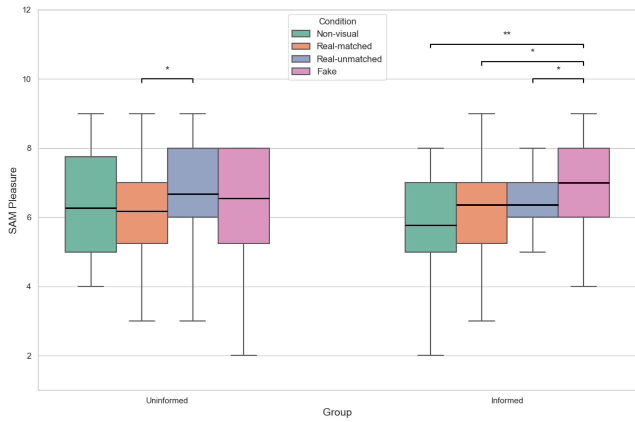
4.2.1 Data-processing and Synchrony calculation. The raw EDA data for each participant was processed using a second-order Butterworth low-pass filter (0.5 Hz) [32] from the `scipy.signal` package to reduce electrical noise. Outliers were replaced using linear interpolation between the nearest valid data points surrounding each outlier group, ensuring smooth transitions in the signal. After interpolating, a moving average was applied to further smooth the data. Finally, to compensate for individual differences in the data, each EDA sample was normalized using a min-max range normalization technique. Neurokit2 [67] was used for further feature extraction. By ruling out incomplete or noisy data records, we have EDA data from 40 recruited concert audience members, from 22 VR participants in the uninformed group (Non-Vis: 22, Matched: 21, Unmatched: 22, Fake: 22), and from 21 VR participants in the informed group (Non-Vis: 21, Matched: 20, Unmatched: 21, Fake: 21). The EDA data were decomposed into two components: the rapidly changing EDA phasic, known as Skin Conductance Response (SCR), and the slowly changing EDA tonic, known as Skin Conductance Level (SCL) [8, 18, 22].

Dynamic Time Warping (DTW) was performed on the EDA phasic and tonic components to calculate the accumulated distance between each VR participant and live audience member. Since the DTW normalized distances did not follow a normal distribution, permutation tests were conducted to assess differences in DTW normalized distances across data visualization and group information conditions. We calculated differences in medians with 10,000 resamples, respectively, using two-sided tests.

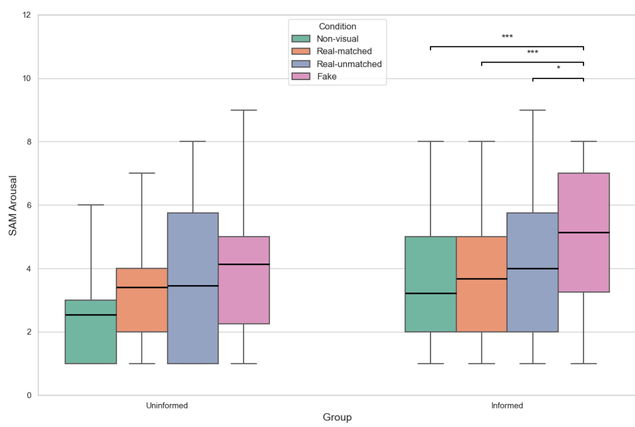
4.2.2 Permutation test results. According to the permutation results, in the uninformed group, the DTW normalized distances of EDA tonic in the Unmatched were significantly smaller than those in the Non-Vis ($p < .05$), the Matched ($p < .01$), and the Fake ($p < .001$). This indicates a higher physiological synchrony in the Unmatched. For EDA phasic, the DTW normalized distances in the Non-Vis were significantly smaller than those in the Matched ($p < .001$) and the Fake ($p < .05$), while the distances in the Unmatched were significantly smaller than those in the Matched ($p < .001$), also suggesting higher synchrony.

In the informed group, the DTW normalized distances of EDA tonic in the Fake were significantly smaller than those in the Non-Vis ($p < .05$), the Matched ($p < .001$), and the Unmatched ($p < .001$), indicating higher physiological synchrony in the Fake, as shown in Figure 6(a). For EDA phasic, the DTW normalized distances in the Non-Vis were significantly smaller than those in the Matched ($p < .001$), the Unmatched ($p < .05$), and the Fake ($p < .001$), as shown in Figure 6(b). Additionally, the distances in the Unmatched were significantly smaller than those in the Fake ($p < .001$), again reflecting higher synchrony.

The EDA tonic component indicates the slow change of skin conductance levels, while the EDA phasic component reflects the quick and prompt change of skin conductance response [8, 12, 21]. Therefore, our findings may suggest the Fake_I could provide VR users with more physiologically similar experiences in terms of long-term and gradual feelings of arousal compared with the short-term fluctuations in certain VR recreation scenarios.

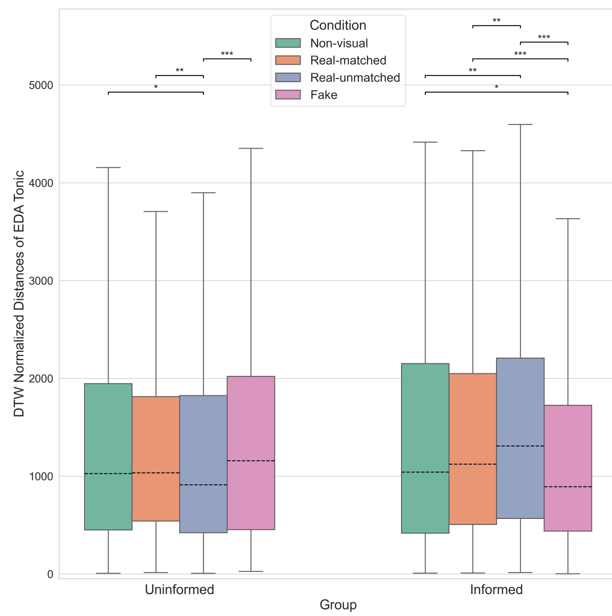


(a) Pleasure levels across data visualization conditions measured using the SAM questionnaire. Unmatched$_U$ is significantly higher than Matched$_U$, and Fake$_I$ is significantly higher than Non-Vis$_I$, Matched$_I$, and Unmatched$_I$.

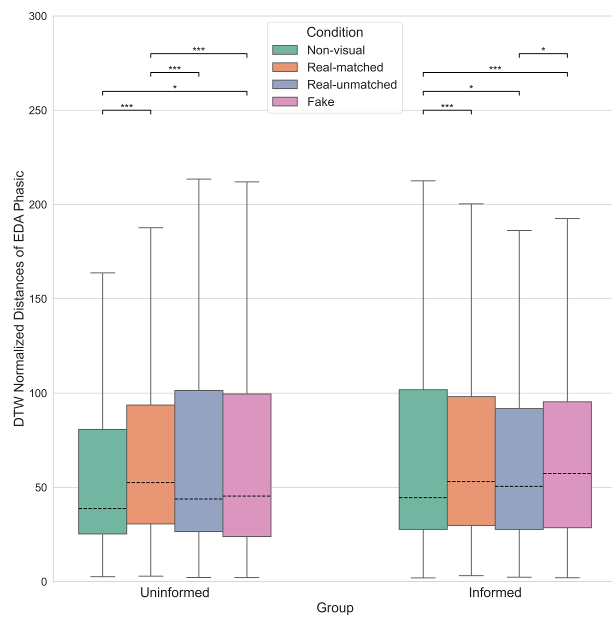


(b) Arousal levels across data visualization conditions measured using the SAM questionnaire. Fake$_I$ evokes significantly higher arousal than Non-Vis$_I$, Matched$_I$, and Unmatched$_I$.

Figure 5: Boxplots of SAM questionnaire results for pleasure and arousal across data visualization conditions.



(a) DTW normalized distances of EDA tonic across conditions. Unmatched$_U$ shows significantly lower distances in the uninformed group, indicating higher physiological synchrony, while Fake$_I$ shows significantly lower distances in the informed group, also indicating higher synchrony.



(b) DTW normalized distances of EDA phasic across conditions. Non-Vis$_U$ shows significantly lower distances than Matched$_U$ and Fake$_I$, indicating higher physiological synchrony. Non-Vis$_I$ shows significantly lower distances, also reflecting higher synchrony.

Figure 6: DTW normalized distances of EDA tonic and phasic across conditions.

5 Discussion

5.1 The prior explanation creates a placebo effect of engagement

The analysis showed that participants in the informed group (I) reported higher engagement than those in the uninformed group (U), $F(1, 42) = 4.61$, $p < .05$. When the Non-Vis was excluded, the informed group also reported a higher sense of co-presence, $F(1, 42) = 7.66$, $p < .01$. This suggests that the prior explanation can enhance VR participants' engagement and sense of co-presence in abstract VR recreation. This aligns to findings in similar studies, outside of physiological data visualization, as the narrative of the study changes perceived performance and or increases trustworthiness, empathy, and effectiveness of a system [7, 80].

The interviews also highlighted the importance of prior explanation. In the absence of a prior explanation, 19 participants in the uninformed group expressed confusion regarding the visual effects, spending a considerable amount of time thinking and "being distracted" during the experience. For example, one participant noted, "At first, I thought it was strange." (Participant 2, U).

This confusion led to some negative emotions, such as fatigue and stress. As one participant shared, "I couldn't understand the firework, what that was. So it made me feel like not so comfortable." (Participant 14, U), while another stated, "I kept thinking about what those things represented, and it made me feel a bit tired" (Participant 3, U).

In contrast, participants in the informed group acknowledged the positive impact of the prior explanation. As one participant expressed, "I think it kind of helped me to imagine if there are other people also in that environment." (Participant 6, I). Knowing that the visuals represented live audience physiological data, they were able to notice more details and observe changes in the data more clearly. Another participant stated, "In the second and third cases, it indeed felt more like they were human, with certain physiological data" (Participant 11, I). These findings resonate with those illustrated by Sanches et al. when documenting the need for a frame of references by participants attempting to interpret a purposefully ambiguous visualization of their own skin conductance over time [87]. Excessive openness in the form of a complete lack of information about what kind of data is visualized and what the intended meaning might be can lead to complete disengagement. Arguably, compared to other studies in which such visualizations were linked to the users' own status or the physiological data of others during co-presence situations [1, 23, 47, 51, 66, 87], in cases such as ours where visualizations aim to foster connections between distributed situations in asynchronous settings this is even more crucial. Qualitative remarks from participants showed how providing a basic explanation was sufficient to shift the perception of the visualized data from distracting noise to meaningful information.

In turn, knowing that others are present may encourage users to engage more fully with the environment, participate in activities, or communicate, all of which can lead to enhanced engagement and co-presence. Participants reported feeling a connection with the audience: "They were making me feel like inside the audience." (Participant 9, I), and "Now because I know there's the connection of like, oh this is the audience, it definitely makes it more meaningful" (Participant 3, I). Another noted, "Because I know this is data from other audience members, I still feel a sense of connection with them, but my greater feeling is that I am receiving information from the audience, rather than transmitting my information to them" (Participant 4, I). Somehow similarly, Aslan et al. reported that, while visualizing their own heartbeat while watching a movie increased immersion, visualizing their partner enhanced their social experience [1]. However, this could result in either emotional resonance or alienation, due to a sense of competitiveness with the other person. On the other hand, in our study, the asynchronous distributed experience of visualizing the physiological data of an unknown audience was only linked to resonance. This could indicate that competitiveness is less likely to arise if participants only connect the visualizations to a generic group of "other people" rather than one individual with a known identity.

Participants also tended to feel that the visual effects in all conditions reflected the activity level of the live audience. As one participant explained, "I was assuming that those who were moving faster were like really excited about the music... it basically showed the excitement of each person, in my opinion" (Participant 18, I).

In the informed group, participants believe that all data visualization conditions represented other audience members, and this belief alone was enough to enhance their engagement and co-presence, even though under Fake audience members are fictitious. This is similar to the "belief creates reality" aspect of the placebo effect.

5.2 Knowledge of others' activity affects emotional response in VR users

The interviews revealed different responses to the Fake between the uninformed and informed groups. Participants in the uninformed group reported negative emotional reactions, while those in the informed group showed more positive responses. This also reflects the placebo effect of the prior explanation, where the belief that the visuals represented audience data positively influenced their emotional experience. According to social facilitation theory [83], the perceived presence of others can enhance an individual's performance or behavior, particularly when the individual believes they are in the company of an active group. When users perceive that others are active in the VR environment, it can foster a sense of engagement or the feeling of "being there together" with others. This heightened engagement can lead to positive emotional states, such as increased pleasure or arousal, as users feel more connected and less isolated.

During the interview, 9 participants in the uninformed reported that the rapidly moving visual effects in the Fake condition were overwhelming. The Fake caused feelings of pressure and discomfort. For example, one participant stated, "It made me feel pressured, very tired" (Participant 20, U). Another participant mentioned, "It kind of distracted me because it was moving too fast" (Participant 6, U).

Further reflecting on the emotional impact, one participant explained, "I felt like a sense of dynamic, and like the visual was very superior to me, so I felt very small and very overpowered by it, like some very apocalyptic or melancholic scenery where I have no meaning" (Participant 13, U). Other participants expressed similar sentiments, such as feeling "rushed because of the pacing" (Participant 18, U).

In contrast, A total of 19 participants in the informed group showed positive attitudes towards the Fake condition, describing the experience as active and dynamic. For example, participants stated that "the vibe is more active" (Participant 7, I) and "more active and dynamic" (Participant 6, I).

Participants also described their feelings as "more engaging" (Participant 8, I) and "excited", believing in the presence of other audience members. As one participant noted, "It feels like I'm really there, but because when the image moves fast, I feel like it's the emotions of other audiences" (Participant 16, I). Another participant remarked, "Seeing this, it felt like everyone was quite active, and it made me feel a bit more active as well" (Participant 1, I).

The belief that the audience was active led them to mirror this perceived state, becoming more active and engaged themselves. they were "carried along" by the perceived high energy of the audience. The key factor driving this response is the social facilitation effect, where the perceived presence of others who are active and attentive encourages individuals to align their own behavior and emotions with the perceived social environment.

The quantitative analysis results also provide support, showing that the Fake$_I$ condition elicited significantly higher pleasure compared to the Non-Vis$_I$ ($p < .01$), Matched$_I$ ($p < .05$), and Unmatched$_I$ ($p < .05$). Similarly, the Fake$_I$ condition evoked significantly higher arousal than the Non-Vis$_I$ ($p < .001$), Matched$_I$ ($p < .001$), and Unmatched$_I$ ($p < .05$).

In the informed group, participants believed that the visuals represented the state of the live audience. When they observed the rapidly moving visuals in Fake, they interpreted this as an indication of a highly active audience, which created a form of social stimulation. This perception psychologically influenced the participants, making them feel as though they were surrounded by a lively and engaged audience. Consequently, they experienced heightened arousal, resulting in increased activity and positive emotions such as pleasure.

The previous study by Eiband et al. has shown how placebic explanations which provide no meaningful information about how an agent operates, still instill a sense of trust that is comparable to the one generated in response to real explanations [25]. Our study shows how the visualization of other people's physiological data is subjected to a similar placebo effect, where animations interpreted as indicating more positive emotions in others, lead to a self-reported sense of engagement, which is even greater than the one measured in the original audience. In our case, the placebo effect of Fake visualizations, can be considered even superior to the one generated by real data. We argue that this occurs thanks to the natural ambiguity of both observation and meaning for abstract visualization of physiological data such as BVP and EDA [47, 87]. On the one hand, participants always chose to interpret the increased liveliness of animation as a sign of enhanced engagement and enjoyment, which is possible because of the natural openness of interpretation offered by the lack of other contextual information. Moreover, the imprecise representation of BVP and EDA using carefully combined lines and spheres allows user to overlay their own explanations to the meaning of the visualization, which can best support the emergence of placebo emotional resonance.

5.3 VR users align their long-term physiological responses with the live audience under Fake visualization

Interestingly, while enhancing pleasure and arousal, the Fake$_I$ also led to significantly higher EDA tonic synchrony between VR users and live concert audience members compared to the Non-Vis$_I$ ($p < .05$), Matched$_I$ ($p < .001$), and Unmatched$_I$ ($p < .001$) conditions. EDA tonic synchrony reflects the alignment of sustained baseline arousal levels, suggesting that the VR users' overall emotional state was more closely aligned with that of the live audience over time. This indicates that the dynamic and engaging visual representation, even if fictitious, can evoke a deeper level of emotional resonance and sustained engagement.

However, the introduction of more active visual stimuli in Fake$_I$ resulted in lower EDA phasic synchrony between VR users and the live audience compared to the Non-Vis$_I$ ($p < .001$) and Unmatched$_I$ ($p < .001$). EDA phasic synchrony captures moment-to-moment fluctuations in arousal, which are often triggered by immediate stimuli. The lower phasic synchronization may indicate that the more intense visual activity created a distraction or introduced conflicting sensory inputs, reducing the alignment of short-term emotional responses.

Additionally, the lower phasic synchronization in Fake$_I$, compared to the Unmatched$_I$ with slower visual changes, suggests that highly dynamic visuals may interfere with the natural synchronization of rapid emotional responses. While the active visual stimuli engage users and enhance tonic synchronization, they may simultaneously disrupt the moment-to-moment physiological alignment, which might tend to be stronger with more stable or slower-changing visuals.

while the data visualization condition using fictitious information effectively enhances engagement, co-presence, and tonic synchronization, it also appears to decrease phasic synchronization due to the introduction of more active visual stimuli. This finding suggests a trade-off: dynamic visual elements that boost sustained emotional resonance and social connection may simultaneously disrupt immediate physiological responses. Understanding this balance can guide the design of VR environments to optimize both long-term engagement and momentary emotional synchrony.

5.4 General Users Lack the Ability to Distinguish Differences in Collective Data

During the interview, a total of 17 participants in the uninformed group and 16 participants in the informed group reported difficulty in describing the differences between the Matched and Unmatched conditions. This may be due to a lack of knowledge and experience related to physiological data, the complexity of interpreting collective data, or the inherent similarity in the concert settings of the Matched and Unmatched conditions. Most of them. expressed that they could not perceive any clear distinctions, with comments such as, "It's really similar. I don't see much of a difference" (Participant 6, I).

Additionally, some participants had an intuitive feeling that the Matched and Unmatched conditions created different atmospheres. For example, one participant noted, "not easy to see the changes, but I can feel it" (Participant 13, I). Another participant elaborated, "It is a holistic feeling; you can't just pick one rhythm or another; it's a whole atmosphere. The position and the ups and downs give me a different experience" (Participant 1, I).

Participants with experience in physiological data analysis could clearly distinguish between the Matched and Unmatched conditions, noting that Matched aligned more with their expectations. One participant mentioned, "B (Matched) should be the original data because it matches what I imagined the data would look like, whether in terms of heart rate frequency or..." (Participant 4, I). Some participants also identified the Fake condition as random data, with one stating, "All three of them are different. Yeah, that's why I think the second one (FAKE) just felt very random" (Participant 3, I). A few participants noticed a time delay in the data visualization: "I felt that there was a slight delay. For example when the music suddenly reaches a climax, it takes a moment for changes to appear… I felt the movement was a little slower than I expected." (Participant 12, I).

Previous work focusing on how individuals use their own physiological data available on fitness tracking applications has shown that knowledge about what these data represent is essential for people to form correct interpretations [87]. Moreover, studies unpacking how deception naturally occurs or is orchestrated in the context of technological interactions are built not only on the ambiguity of designed representations or methods [24, 84, 87, 115], but also on the lack of knowledge that individuals have about how a particular technology operates, or what physiological data represent [56, 94, 115]. Placebo effect studies in medicine have shown that such mechanisms are effective even in *"open-label"* trials, where people are aware of being administered a *fake* treatment, are still effective [15]. Although the number of participants in our study who correctly identified UNMATCHED and FAKE data is too small to carry out differential analysis on their physiological responses, their qualitative comments seem to indicate a preference for MATCHED conditions. In turn, this could have broader implications for the development and application of purposeful placebo interactions in HCI with their impact being directly affected by the users' knowledge of how technology or data representation are expected to behave in particular contexts.

6 Limitations and Future Work

First, for the uninformed group, the reason why the UNMATCHED condition performed better than the others remains unclear. 8 participants expressed a preference for the UNMATCHED condition, believing its visuals best matched the atmosphere of the music.

According to participant interviews, their lack of understanding of the VR recreation context and data visualization made it difficult for them to differentiate between the UNMATCHED and MATCHED conditions. Their preference for the UNMATCHED condition was often described as an instinctive, subjective feeling. As another participant described, "The reason it felt more relaxing to me was that it provided a reference without forcing me; it was more in line with my current feelings." (Participant 20, U). This could be due to the movement speed of the visuals aligning with their expectations (participants noted that the speed in the FAKE condition was too fast and irritating, while in the MATCHED condition, it was too slow and boring). One participant commented, "I liked the last one (UNMATCHED), the speed was moderate... one was faster, another was very slow, and I preferred the middle one... I feel the moderate one fits the music better and gives me an overall sense of atmosphere" (Participant 9, U). It could also be that the UNMATCHED condition created an atmosphere that participants felt was most in tune with the music. However, the reasons why the UNMATCHED condition enhanced pleasure and increased EDA tonic synchrony in the uninformed group remain ambiguous and require further exploration.

Second, in the informed group, we intentionally did not tell participants that the data visualization in the FAKE condition was randomly generated rather than based on the real concert audience's data. While a few experts with experience in physiological data research recognized it was not real physiological data, most participants reported that they believed it represented the live audience's state and felt that the audience appeared more active under the FAKE condition than in others. The enhanced engagement and co-presence in the FAKE condition suggest a possible placebo effect. This leads to the question that if participants would respond differently if being informed and therefore be aware about the nature of the data in the data visualization conditions. How would this impact their subjective perception and physiological responses? Can a placebo effect still be achieved when being aware of the placebo effect itself? Investigating this condition could help us better understand the underlying mechanisms of the FAKE condition's effectiveness. Therefore, changing the context of when and when not a placebo effect for physiological measures can be intentionally used by designers. Another potential direction for future research is to generate multiple visualizations from the same physiological data set by adjusting visual parameters. This approach could help explore whether certain visual effects based on real data might induce a placebo effect. Additionally, new conditions could be introduced in user studies: (1) computer-generated visualizations and (2) traditional visualizations designed by experts. By refining the Fake condition, these studies could further investigate the role of human involvement in shaping the placebo effect. Together, these potential directions would provide deeper insights into the underlying mechanisms of the placebo effect and expand its applications, offering valuable benefits to both designers and researchers.

7 Conclusion

We see a rise in usage of physiological data in HCI research, from analyzing a user's engagement to enhancing their experience over visualizations. The focus often lies on individual users and live feedback. In our paper, we evaluate the effectiveness of using other people's physiological response by comparing it to real and fake data.

We utilize physiological data visualization to replicate a concert audience in VR by representing their physiological data. In a user study ($n = 44$) we compare the visual representation of four physiological data sets, in the form of concert audiences physiological data, an unmatched instance of real data from a different context, randomized fake data, and lastly no visualization.

We found that when users are unaware of the meaning of the visualization, they show a tendency to feel confused. Additionally, when presented with randomized FAKE data, they feel distracted as well due to the high amount of visual movement.

However, when the **users are informed** that the visualization represents other people's responses during the same experience, the **visualization results in an increased engagement and co-presence**. Additionally, **randomized FAKE data creates a placebo effect of the presence of other people**. While unaware about the fake nature of the data, users interpreted the randomly generated FAKE data as a very active audience, due to the high amount of movement in the visualization. This in turn results in a more active and engaged response from the users themselves.

Therefore, **a placebo effect in physiological data visualization can be found to have a significant effect on the perception and response of the user**. Furthermore, we discuss and suggest guidelines that allow future designers and researchers to leverage these findings. **Data in ad-hoc experiences need to be carefully chosen to not negatively affect the experience**. Alternatively, it is **possible to create a placebo effect in experiences where data visualizations can be explained**. Future designers and investigations will need to consider if the placebo effect is also applicable if the user is aware of the authenticity of the data being presented.

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