BizarreVR: Dream-like bizarreness in immersive virtual reality induced changes in conscious experience of reality while leaving spatial presence intact

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ABSTRACT

Differences in conscious experience of reality occur between waking, dreaming, and psychotic states. Between these states, there are systematic differences in the judgment about the reality of the experience when being confronted with bizarre breaks. However, the mechanisms underlying experience of reality in these different states are still unknown. To investigate the effect of bizarre breaks on experience of reality during the wake state, we propose a new paradigm using dream-like bizarreness and immersive virtual reality. Results showed that the realistic non-bizarre virtual environment induced high levels of reality judgment and spatial presence, whereas the confrontation with bizarre breaks induced high levels of experienced bizarreness. Moreover, experienced bizarreness significantly reduced reality judgment in both the bizarre and the realistic condition. Further, there was no effect of bizarre breaks on spatial presence. These results provide proof of concept for the new method to elicit natural bizarre experience within a realistic scenario.

1. Introduction

Successful interaction of a human being with the external world crucially depends on the ability to evaluate whether and how a certain conscious experience is informative about the external world. If an experience appears real to the human being, it is commonly judged as corresponding to external events and thus as experience of something real. However, deviations in the judgment about the correspondence between experience and external world occur naturally in the sleep state such as during dreams, or at the transition from wake to sleep (hypnagogic states), as well as in the wake state during psychotic conditions such as hallucinations or dissociative states like derealization. Especially, wake to sleep transitions and dreams are characterized by vivid conscious experiences that appear real (Nir & Tononi, 2010; Rosen, 2018) although they are completely independent of input from the external world. Only upon awakening, the internal nature of the experience becomes apparent and the ability to differentiate dreaming from waking experience is restored retrospectively. Moreover, these altered states of experience can go along with bizarre breaks described by incongruency in

semantic coherence of the experienced events, discontinuity in the stream of events, or violation of general world-knowledge like physical laws. In dreams, bizarre elements can come as a break within an otherwise rather mundane and realistic environment. Nevertheless, bizarre breaks occurring in dreams or hallucinations are in general uncritically accepted and judged as real by the experiencing individual (Rosen, 2018; Scarone et al., 2008). Since there is this systematic deviation in experience of reality when confronted with bizarre breaks between the normal waking state and altered states like dreams or hallucinations, bizarre breaks are an interesting tool to investigate the mechanisms that underlie the experience of reality.

1.1. Theoretical approaches to conscious experience and experience of reality

Potential neural mechanisms underlying conscious experience have been described by a number of theories (cf. Frith, 2021). What is common to most of the major theories such as Global Workspace Theory (Dehaene et al., 2003), Integrated Information Theory (Tononi, 2008), or Higher-Order Theories (Lau & Rosenthal, 2011) is the assumption that conscious experience emerges from a certain kind of interaction between various large-scale brain networks mainly in frontal and parietal areas depending on the theory. Moreover, being able to make judgments about the reality of an experience requires some form of meta-consciousness or self-monitoring, which has been related to activity in higher-level cortical areas (Frith, 2021). This form of meta-consciousness would be similar to a secondary higher-level process in a dual process approach (cf. Frith, 2021).

Aiming to explain changes in experience of reality, the predictive processing approach to conscious experience (Clark, 2013; Hohwy, 2020; Wiese & Metzinger, 2017) is of interest because its hierarchical nature entails a form of higher-level meta-consciousness. In particular, predictive processing provides a systematic mapping between the neural mechanism and the phenomenology of conscious experience (Hohwy & Seth, 2020; Seth & Hohwy, 2020). Further, predictive processing theory has been used previously to explain altered states of experience like hallucinations (Cole et al., 2020; Sterzer et al., 2018) or dreaming (Hobson et al., 2014, 2021). Within the predictive processing framework, conscious experience is the result of an inference process that compares actual sensory input with predicted sensory input. Predictions are based on an internal hierarchical generative model about the hidden causes of sensory signals. If predictions do not match the sensory input, a prediction error occurs, and the unpredicted part of the incoming sensory signal reaches higher levels in the hierarchy. The prediction error signal carries information about the validity, i.e. the precision, of the prediction and the sensory input. This allows the model to perform a precision-weighted update to generate new predictions or to get new sensory input in order to minimize the prediction error on the long run.

As described above, meta-consciousness processes such as reality judgment occur at higher-level cortical areas. Hence, bizarre breaks will be processed at higher-level cortical areas as well. Prediction errors elicited by bizarre breaks will thus occur on higher levels of the hierarchical predictive model. If this error elicited by bizarre breaks cannot be explained by new predictions or new sensory input, it may lead to the experience of bizarreness and unreality. This would be the functional equivalent of a persisting mismatch between high precision sensory input and high precision higher-level predictions. During dreams and hallucinations, however, bizarre breaks are generally experienced as real and non-bizarre. It is unclear whether there are no prediction errors on higher levels of the hierarchy during these altered states, or whether errors occur but they are processed in a different, aberrant way.

An optimal way to investigate the effect of bizarre breaks on conscious experience of reality is to create an experimental paradigm able to elicit natural bizarre breaks in a realistic scenario during the normal waking state. Using such a paradigm will make it possible to understand better the differences in processing bizarre breaks during the normal waking state and during altered states, such as in dreams or psychotic conditions. This type of comparison will be highly relevant to investigate commonalities and differences between the functional role of dreaming and dysfunctional states like psychosis. In the future, such an approach might help to find a general mechanism underlying the experience of reality.

1.2. Investigating bizarre breaks in a naturalistic and realistic scenario

Investigating conscious experience of reality has been facing several obstacles. First, comparing altered experience in dreams with regular experience during wake is problematic, because the experiences occur during different vigilance states of the large-scale brain networks (Aru et al., 2020; Nir & Tononi, 2010). This makes it difficult to disentangle the effects of experience from those of vigilance. If conscious experience emerges from brain network interactions, we will observe that differences in experience are related with different states of the networks and their interactions. Thus, to compare the basic mechanisms underlying experience of reality with experience of unreality, the state of the networks and their interaction should be the same over the different conditions of the paradigm. In short, a useful paradigm should control for vigilance by investigating differences in experience within the same vigilance state.

Second, experience is also influenced by prior knowledge about the world and the respective expectations, which might differ between individuals. According to the psychosis continuum theory (Van Os et al., 2009), alterations in experience of reality are to a certain degree already present within the general population. Proneness to psychosis-like experience such as hallucinations was associated with a loosening of semantic associations (Erb et al., 2020; Kiang et al., 2010), which might influence the effect of bizarre breaks. Thus, it is necessary to collect additional measures for individual tendencies in experience, such as the tendency towards hallucinatory experience.

Third, bizarre breaks like those during altered states usually do not occur during the unaltered wake state. However, a form of naturally occurring bizarreness is necessary to investigate the processing of bizarre breaks during wake. Since dreams, which include a varying amount of bizarre breaks (Nemeth & Bányai, 2021; Rosen, 2018), naturally occur in every human, dream bizarreness serves as a good model for bizarre breaks. Dream bizarreness is a common feature of dream content and is characterized by events, places,

characters or actions as well as thoughts or emotions, which contain incongruent, implausible, impossible, uncertain or discontinuous elements (Revonsuo & Salmivalli, 1995; Williams et al., 1992). Although previous research debated about whether dreams are generally bizarre or realistic (for a review see Rosen, 2018), we will focus exclusively on the incoherent nature of dream bizarreness independent of its general frequency in dreams.

Finally, inducing bizarre experiences in a waking state has been problematic in terms of how to present bizarre stimuli. Traditionally, presenting stimuli on a regular computer screen for desktop PCs with a low level of immersion does not create the necessary level of presence, i.e. the feeling of being there in the presenting medium (Slater, 2009; Wirth et al., 2007). In other words, experiencing stimuli presented on a regular computer screen is not comparable to the immersive bizarre experiences, which occur during dreams or psychosis.

Thus, to investigate the effect of bizarre breaks on conscious experience of reality in a natural awake context, a paradigm should be able to present natural bizarre stimuli within a realistic and naturalistic environment while at the same time reducing the impact of potentially confounding variables. With common experimental setups including a regular computer screen, such an experimental design has not been possible.

1.3. Potential of immersive VR and importance of presence

A solution to finding a suitable experimental design is to use highly immersive Virtual Reality (VR). Immersive VR technology allows for a VR illusion, in which the user has the feeling of being there in the virtual environment (VE). In such a VE, the user is likely to accept the displayed content as really happening, i.e. as realistic experience, which leads to natural behavior (Slater, 2009, 2018). Thus, immersive VEs are key to investigate the phenomenological aspect of experience of reality in real-time.

VR illusion is described by the concept of presence. According to Slater (2009), presence is based on the illusion of place and the illusion of plausibility. A suitable measure for place illusion is spatial presence within the VE (Wirth et al., 2007), which describes the feeling of being physically transported and located in a VE. In predictive processing terms, the experience of conscious presence of the self being located within the world emerges with the successful suppression of prediction errors by informative body-related somatosensory predictions (Seth et al., 2012). A highly immersive VR system that provides sensory feedback in line with the somatosensory predictions will lead to a strong experience of conscious presence due to suppressed prediction errors. These somatosensory predictions should take place on lower levels of the hierarchical model and accordingly on lower cognitive levels. Therefore, a highly realistic and immersive VE serves the conditions for conscious spatial presence. Since implausible and impossible bizarre breaks should affect higher cognitive levels, it is likely that bizarre breaks have no influence on spatial presence. Indeed, implausible elements in immersive VR had no influence on spatial presence (Hofer et al., 2020). A component influencing spatial presence is suspension of disbelief (de Gelder et al., 2018), which describes the user's willingness to believe or the intentional avoidance of disbelief in the reality of the VE in terms of choosing the virtual over the real world as a reference frame for the current experience (Wirth et al., 2007). This makes it easier to forget about the virtuality, which then facilitates immersion into the VE. Therefore, suspension of disbelief should be considered when assessing spatial presence.

A suitable measure for the illusion of plausibility in VR is the concept of reality judgment (Baños et al., 2000), which asks for the judgment about the reality and plausibility of the VR experience. It is an additional factor to (spatial) presence and describes independent aspects of experience of reality in VR. This concept asks for higher-level cognitive judgments, similar to a secondary process in a dual process system or meta-consciousness. As Baños et al. (2000) discussed, it is useful for investigating "How do people decide whether something is real or not?" (p. 332). Thus, reality judgment is a good indicator of experience of reality in VR.

The real environment can be used to increase the level of presence in VR. Using a virtual copy of the experimental room as transition into the virtual world resulted in higher levels of presence (Steinicke et al., 2009). Moreover, accurate sensory feedback by real counterparts for virtual objects increased the perceptual plausibility and thus presence in a substitutional reality setup (Simeone et al., 2015). Hence, in order to achieve a plausible and realistic VE allowing for an easy transition into the virtual world, the best choice is to create an exact virtual copy of the actual experimental room including all objects at the exact same place as their real counterpart. Since there is some evidence that motion sickness and technology-related bodily discomfort has a negative effect on presence in VR (Weech et al., 2019), VR sickness should be considered as a confounding factor.

Up to now, no study has investigated the effect of dream-like bizarre breaks on conscious experience of reality in a natural immersive VE. Only one study used dream-like bizarreness in VR, but as a trigger for repeated reality testing during wake, and the authors investigated its effect on subsequent lucidity in dreams during sleep (Gott et al., 2021). They did not investigate the effect of bizarre breaks on immediate conscious experience in the normal wake state. Yet another study examined the effect of hallucination-like visual reality alterations on experience of reality to determine a sense of reality (Drori et al., 2020). While they used immersive virtual reality, participants were stationary and did not move around in the VE, which might have reduced spatial presence. Moreover, participants gave a reality judgment after each hallucination-like experience over several trials. By that, participants potentially became aware of the virtual nature of the experience and presence was interrupted repeatedly, which in turn might have affected their reality judgement. Their experimental procedure also differs from a natural stream of events like in hallucinations or dreams.

We propose a new approach for the systematic investigation of conscious experience of reality. Dream-like bizarre breaks will be presented within a highly naturalistic and realistic immersive VE. Additionally, we will assess conscious experience of reality and bizarreness. The proposed approach contains an exact virtual copy of the actual experimental room, a familiar office room. Participants will be free to move in the VE at any time and receive accurate auditory and haptic feedback by the real counterparts of the virtual objects. Additional dream-like bizarre elements are included in the virtual experimental room. Participants will experience bizarre breaks while feeling spatially present. Moreover, we provide a natural stream of events with successive and implicitly self-elicited

bizarre breaks. This renders the scenario comparable to dream experience. Thus, with this paradigm, we are able to investigate a global state of conscious experience.

1.4. Aims and hypotheses

We first present the novel BizarreVR paradigm that allows for a systematic manipulation of experience of reality with two conditions: one realistic (RealisticVR) and one bizarre condition (BizarreVR), where the bizarre condition includes additional dream-like bizarre elements. Second, we aim to provide evidence that the paradigm elicits differences in the quality of conscious experience as being real or bizarre. This paradigm is an efficient way to investigate the effect of dream-like bizarre breaks on conscious experience systematically in the normal wake state, while being under the illusion of virtual realness.

We expect that experiencing dream-like bizarre events iteratively over time will lead to an increased experience of bizarreness and reduce the experience of reality. We hypothesize that experienced reality will be higher in the realistic condition without bizarre breaks compared to the bizarre condition including bizarre breaks. Likewise, we hypothesize that experience of bizarreness will be higher in the bizarre condition compared to the realistic condition. Moreover, we expect a negative correlation between experienced bizarreness and experienced reality. Furthermore, we will investigate whether tendency towards hallucinatory experience has an influence on experience of reality. We expect that participants who are more prone to psychosis-like experiences such as hallucinations will differ in their processing of bizarre breaks such that they experience breaks less as a violation of the semantic coherence in the environment. Therefore, we hypothesize a positive correlation between the tendency towards hallucinatory experience and the experience of reality as well as a negative correlation with experience of bizarreness in the bizarre condition. We will also test whether the presented bizarre content has any influence on the participants' perceived VR illusion in terms of spatial presence. Bizarre breaks in semantic coherence are expected to affect higher-level cognitive processes whereas spatial presence is based on lower-level processes. Thus, we expect no effect of bizarre breaks on spatial presence. Finally, we will compare qualitatively reports of experienced bizarreness in the dream-like bizarre VE with reports of bizarreness in rapid eye movement (REM) sleep dreams. Assessing phenomenological similarities and differences in experience between our paradigm and dream experience will be a useful addition for the overall evaluation of the paradigm presented in this study.

2. Method

2.1. Participants

Forty-seven participants were enrolled into the study. Two of them were dropouts and six were excluded due to technical problems during the experiment. Data of the remaining 39 participants ($n_{female} = 29$; $M_{age} = 23.45$ years; $SD_{age} = 4.62$ years; range $19 - 39$ years; one left-handed) were included into analysis. All participants were students from the University of Bern or external students. Inclusion criteria were age between 18 and 40 years, native or bilingual speaker of German, normal or corrected vision, and a regular sleep rhythm (to exclude the influence of sleepiness on experience). Exclusion criteria were severe nausea in VR (value > 11 on Fast Motion Sickness Scale; FMS, Keshavarz & Hecht, 2011), implanted medical devices, hearing problems or hearing aids, severe tinnitus, history of neurological or psychiatric disorders, current intake of psychoactive substances or cardiovascular agents, and EEG-incompatible hairstyle (EEG data were not part of the current study, see Section 2.2). All participants took part voluntarily and gave written informed consent prior to participation. Undergraduate students of Psychology received course credits as compensation for their participation. The study has been approved by the Ethics Committee of the University of Bern (approval no. 2019-07-00003).

2.2. VR setup

The VEs and the experimental procedure were developed using Unreal Engine 4.21 (UE4, Epic Games, 2018). 3D content was created using Maya 2018 (Autodesk Inc., 2018), Blender 2.79b (Blender Foundation, 2017), or were customized assets from the UE4 Epic Store. The experiment was presented via the HTC Vive Pro Eye head-mounted display (HMD) with a display resolution of 1440 × 1600 pixels per eye, a refresh rate of 90 Hz, and a 110° field of view, combined with the HTC Vive Wireless Adapter. Room-scale tracking of the HMD was based on four HTC SteamVR Base Stations 2.0 mounted at the four corners of the room at a height of 2.25 m. This enabled participants to walk naturally and wireless all across the real and virtual office room. Participants did not have to hold controllers throughout the whole experiment in order to enhance their natural behavior. To avoid reflections that distract the HMD tracking system, all glossy surfaces were covered or replaced. The wireless VR system was combined with EEG equipment. Although the EEG data are not relevant in the context of the present study and will be reported elsewhere, the recording equipment might have had an influence on experience, since the EEG system was still wired for technical reasons. To avoid the awareness of the cable while navigating in VR, participants were wearing a hiking backpack containing the EEG amplifiers and battery pack, to allow a maximum of free-range movements despite the required glass fiber wires of the EEG system. Moreover, a slide rail mounted to the ceiling of the room served as guidance in order to keep the cable away from the participant, the VR equipment, and the EEG backpack (see Appendix A1).

For the experimental procedure, the following VEs were designed: The 'Virtual Office-Room' (Fig. 2), an office-room environment, which served as basis for the two conditions RealisticVR and BizarreVR. The exact layout and all furnishings and objects of the real office-room were replicated and located in their original position in the virtual office room (see Fig. 1), except for the objects that belong to the VR setup. Between conditions, participants were able to rest in the 'Virtual Resting-Environment', which was a plain world

containing only a simplistic floor and the black stool. Prior to the experiment, participants were trained for the task in the '*Virtual Training-Environment*', which was a plain world containing only a simplistic floor, three white walls (two opposite walls aligned with the two longer walls of the real room), a black stool, and two geometric figures as example objects on top of rectangular pedestals. A white beam was painted on the floor.

2.3. Dream-Like bizarre elements and 3D representation

The same 3D office objects were present in both conditions. However, in the BizarreVR condition, the following six objects contained additional dream-like bizarre elements: book, telephone, window, pen, picture, and jacket (example objects are shown in Fig. 3; for a list of all manipulations see Table 1). In order to define dream-like bizarre elements for the virtual office room, we analyzed written dream reports of representative dreamers to detect the most frequent objects. Dream reports were selected from the database DreamBank.net by Domhoff & Schneider (2008) and from an unpublished Master's thesis at the University of Bern (von Dach, 2017). We chose those most frequent dream objects, which were related to the office context of the VE. Then, we manipulated the identified objects according to a common definition of dream bizarreness. In the following, the steps for identification and implementation of the dream-like bizarre stimuli are described.

Criteria for selection of dream reports were German language, not older than 1990, and dreamers should not be older than 45 years to be representative for our study sample of German-speaking young adults. This led to a total of 1470 dream reports. Using the Python Package '*nltk*', the reports were first tokenized, i.e. separated into single sentences, and then separated into single words. Next, useless words other than nouns and verbs were removed using the stopwords list in German. The remaining single words were then stemmed to the grammatically shortest word stem. Finally, the frequencies of these stemmed words were calculated. Further, the resulting word-stem list sorted by frequency was reduced to words with a frequency ≥ 5 and typical office-related words were selected manually. From the remaining words, we chose the six most frequent ones, which already had a physical representation in the office room. These resulting six objects were used in the VE for the realistic condition and were manipulated into dream bizarre elements in the bizarre condition.

We then manipulated the six objects according to Williams et al. (1992), who use a systematic and fine-grained definition of dream bizarreness that suits our aim to manipulate prototypical bizarreness. Their scoring system for dream bizarreness consists of two-steps: First, the "locus" of bizarreness is identified, which was either the plot (characters, objects, actions, place, or time), the thoughts, or the emotion of the dreamer; and second, the "level" of bizarreness is identified, which was 1) "incongruent", 2) "vague", or 3) "discontinuous". In our setup, only elements regarding the plot such as "place" and "object" could be manipulated in a reasonable way, which limited our manipulation to these two aspects. We avoided manipulations regarding the accuracy of the sensorimotor feedback in the virtual environment, which could induce VR sickness, to maintain a strong VR immersion. Thus, we chose the following manipulation for our six elements as listed in Table 1.

All six 3D representations of bizarre elements were manipulated along the discontinuity axis, such that, in the BizarreVR condition, the objects transformed from realistic to bizarre upon approach (<1.7 m) and with eye fixation, while the participant was walking through the room. All bizarre transformations started with a delay of 1 s and took 2 s to accomplish. Five of the six objects developed into an incongruent element, while one object developed into a vague element. Transformations remained active such that, at the end of the condition, all bizarre transformations were visible simultaneously. Examples for the 3D representations are shown in Fig. 3. All 3D representations are depicted in Appendix A3.

2.4. Experience questionnaires

2.4.1. Experience of reality and bizarreness

We assessed conscious experience of both reality and bizarreness for the two virtual conditions. The measure for experienced reality was the 8-item subscale 'Reality Judgment' from the '*Reality Judgment and Presence Questionnaire*' by Baños et al. (2000). Items were
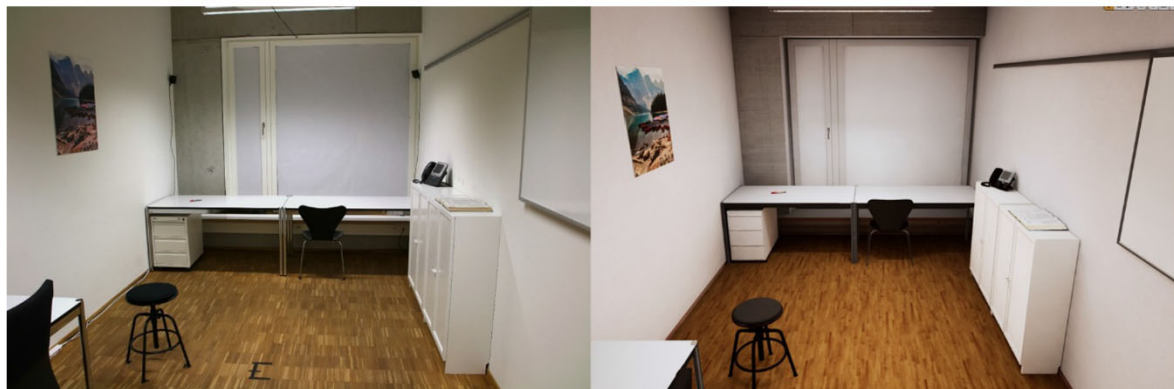

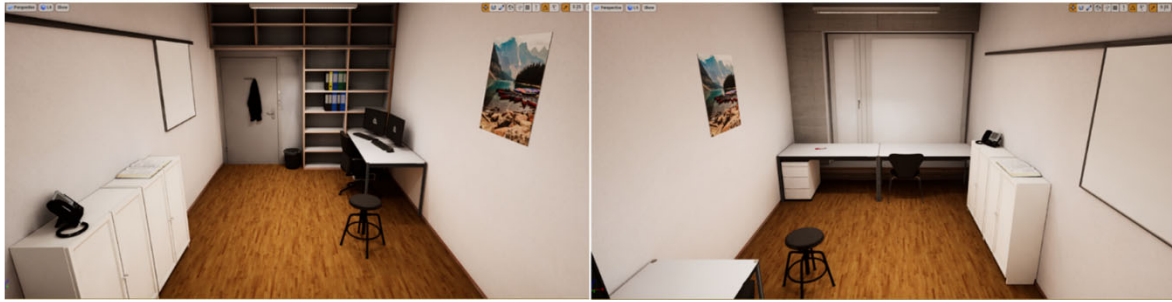**Fig. 1.** Real office room (left) vs. exact virtual copy of the office room (right).

Fig. 2. Objects in the Virtual Office-Room. View to the south (left) and to the north (right).
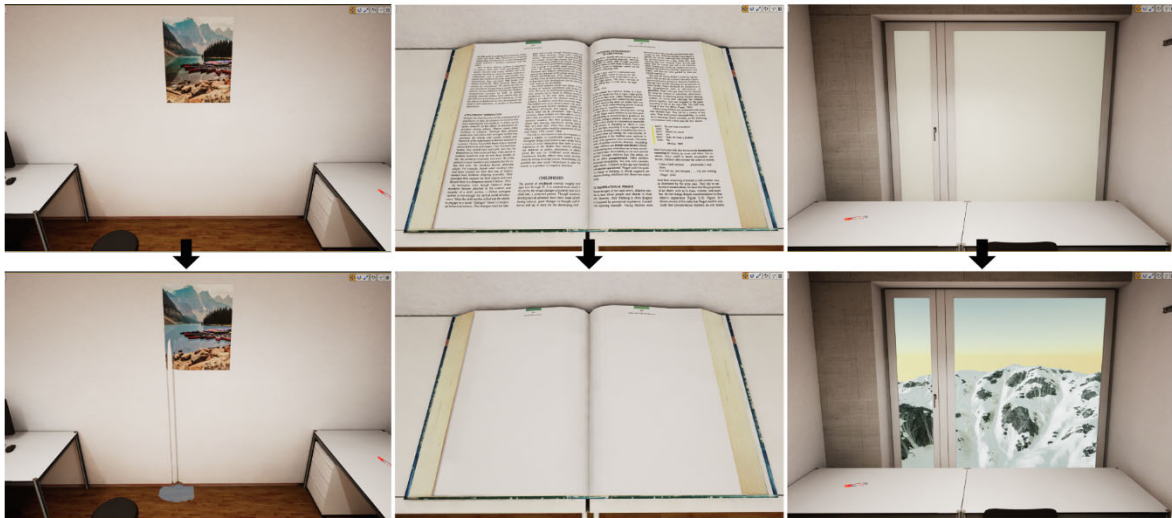

Fig. 3. Three examples for dream-like bizarre elements. 3D office objects in the RealisticVR condition (top) and transformed objects containing bizarre elements in the BizarreVR condition (bottom). Painting (bottom left): locus of bizarreness was 'object'; the bizarreness level was 'incongruency'. Book (bottom middle): locus of bizarreness was 'object'; the bizarreness level was 'vagueness'. Window (bottom right): locus of bizarreness was 'place'; the level of bizarreness was 'discontinuity'. All six bizarre objects were discontinuous, since they transformed upon approach and fixation.

Table 1
Dream-like bizarre manipulation of six objects or places that are frequent in dreams.

Object	Realistic	Bizarre	Place/ Object	Discon- tinuous	Incon- gruent	Vague
Book	Open psychology textbook	Text disappears	Object	✓		✓
Telephone	Black office telephone	Material switches into pink plush, smoke signs come out of moving handle	Object	✓	✓	
Picture	Picture of mountain and lake on the wall	Water starts draining out of lake to the floor	Object	✓	✓	
Pen	Marker-Pen on table	Starts to grow to an unrealistic size	Object	✓	✓	
Jacket	Jacket on hook	Gravitational force of jacket slowly drifts to the right	Object	✓	✓	
Window	Huge office window with white cover	White cover disappears, panoramic view from above on mountain peaks indicates shift of room location	Place	✓	✓	

answered on an 11-point Likert scale ranging from 0 = 'not at all' to 10 = 'absolutely'. To assess experienced bizarreness, we modified the subscale 'General Reality Orientation' from the '*Subjective Experiences Rating Scale*' (SERS; Kahan & LaBerge, 2011), a questionnaire asking for experience while dreaming compared to waking. In their study, participants were prompted throughout waking or during REM sleep while dreaming to rate their experience. We added three items according to the three levels of the previously introduced dream bizarreness definition. Moreover, we removed items related to 'atypical actions' and 'other's actions', since the participants' behavior was forced to be typical and there were no other actors in the VE. The final scale for 'Experienced Bizarreness' comprised 9-items, which were answered on a 5-point Likert scale (1 = 'not at all' to 5 = 'absolutely'). For both scales, we calculated mean scores for

each participant and condition.

2.4.2. Spatial presence

We assessed spatial presence using the two 8-item subscales 'Self Location' and 'Suspension of Disbelief' of the '*Spatial Presence Questionnaire*' (MEC-SPQ; Vorderer et al., 2004) with inserting 'virtual environment' into the medium placeholder of the item text. Both scales were answered on a 5-point Likert scale (1 = 'I do not agree at all' to 5 = 'I fully agree'). Mean scores for both scales were calculated for each participant and condition.

2.4.3. VR sickness

As a possible confounding factor, we assessed the amount of VR sickness in the two conditions with the 9-item '*Virtual Reality Sickness Questionnaire*' (VRSQ; Kim et al., 2018), using a using a 4-point Likert scale (1 = 'not at all' to 4 = 'very'). We calculated mean scores for each participant and condition. Then, we calculated the mean of both conditions for each participant as score for general VR sickness.

2.4.4. Hallucinatory experience

To assess tendencies towards hallucinatory experiences, we used the 12-item '*Launay-Slade Hallucination Scale*' (LSHS-R; Lincoln et al., 2009) with a 5-point Likert scale (0 = 'certainly does not apply to me' to 4 = 'certainly applies to me'). We calculated the sum score for each participant.

2.5. Procedure

Participants took part in two sessions on two separate days, which were on average 6.77 days (SD_{days} = 3.71) apart. Both sessions took place in the same quiet office room at the University of Bern. For all participants, the first session started in the afternoon, and the second session always started at 9 am.

2.5.1. Session 1 – Screening and preparation

In a first session, we screened participants for eligibility and participants gave informed consent prior to inclusion. Afterwards, participants filled in questionnaires asking for demographics and their individual tendencies towards hallucinatory experiences. All questionnaires were presented on a computer screen via the browser-based survey platform Qualtrics Research Suite (Qualtrics, 2019). To exclude severe VR sickness, we asked participants at the start of their VR training to walk up and down on a white plank painted on the virtual floor of the '*Virtual Training-Environment*' while looking around, and then asked them about their acute state of nausea using the Fast Motion Sickness Scale (FMS). Answers of all participants were below the critical exclusion value. Afterwards, participants performed a VR training task as preparation for the experimental procedure in session 2.

2.5.2. Session 2 – VR experiment

The procedure of the second session included the preparation of the VR and EEG setup and two experimental blocks. At the end, participants filled in the questionnaires to evaluate the experience in the two VR conditions.

Preparation. Preparing the combined VR and EEG setup included preparation of the electrode cap and the EEG backpack. This was always performed by two experimenters. During preparation, the participant received written and oral instructions about the VR task. Then, the participant carefully put on the HMD, adjusted its fit, and finally put on the equipment backpack (see Appendix A2 for the participant's final setup).

BizarreVR paradigm. Block 1 and 2 represented the two conditions 'RealisticVR' and 'BizarreVR' of the VR paradigm. The order of conditions was counterbalanced between participants, while controlling for age and sex. Both blocks followed the same procedure, the only difference were the manipulated six 3D object stimuli, which stayed either realistic or transformed into bizarre objects.

In each of the two blocks, participants first freely explored the '*Virtual Office-Room*', starting from the same position. All were absolutely naïve about the kind of VE they would see next. Before the start of the free exploration task, participants were reminded of the instructions as follows: 1) to explore thoroughly the subsequent virtual room, 2) to look closely at all objects and room parts, and 3) to remember them for later questions (this was a pseudo-task). Additionally, they were told to 4) go close to all visible objects, 5) to avoid fast (head) movements while walking freely across the virtual room, 6) to explore as long as they wanted and to do so abundantly. Finally, they were instructed 7) to sit on the touchable virtual black stool after being sure of having seen all objects and having approached all objects closely. Participants then started exploration immediately after the virtual office room appeared in the HMD. An exemplary video for the exploration task can be found in Appendix B. After participants ended their exploration by sitting down on the black stool, an auditory semantic priming task (see Kutas & Federmeier, 2011) was presented for 7 min via built-in headphones of the HMD. After the semantic priming task, a 2 min resting state EEG was recorded. Throughout the whole exploration and listening task, the experimenter stopped all interaction, avoided physical contact with the participant, and behaved quietly to prevent breaking the virtual presence of the participants. The semantic priming task and the EEG recordings are not relevant in the context of the present work. At the end of the first block, participants were transferred to the '*Virtual Resting-Environment*', where they could have a break and relax before the second block started.

Experience rating. After the second block, participants removed the HMD and re-entered the real office room. The electrode cap was removed and participants filled in the digital questionnaires for Reality Judgment, Experienced Bizarreness, Spatial Presence, and VR Sickness during the two VR conditions.

2.6. Statistical analysis

To proof the efficacy of our manipulation, we used a one-way within-subject design to investigate the influence of the 2-level factor 'Degree of Plausibility' ('RealisticVR' vs. 'BizarreVR') on experience ratings. Dependent variables were experience of reality and bizarreness and spatial presence in the immersive VEs. To test for differences in experience between the two conditions 'RealisticVR' and 'BizarreVR', we conducted paired t-tests (two-tailed) for the variables 'Reality Judgment', 'Experienced Bizarreness', 'Self Location', 'Suspension of Disbelief' and 'VR Sickness'. If the assumption of normality was violated, a Wilcoxon signed rank test was performed. To control for confounding factors such as an effect of order due to the counterbalancing and VR sickness, additional ANOVAs with one within-subject factor 'Degree of Plausibility' (RealisticVR vs BizarreVR), one between-subjects factor 'StartCondition' (RealisticVR vs BizarreVR), and the covariate 'VR Sickness' were calculated for the variables 'Reality Judgment', 'Experienced Bizarreness', 'Self Location', and 'Suspension of Disbelief'. To test for a functional relationship between experience of reality and experience of bizarreness, we fitted a linear mixed model using the lme4 package for R (Bates et al., 2015) to predict 'Reality Judgment' with 'Experienced Bizarreness' and 'Condition' as fixed effects. The model included 'Participants' as random effect. Moreover, we assessed participants' tendency towards hallucinatory experiences to capture the influence of individual differences. To analyze the relationship between hallucinatory experiences and experience of reality during immersion in the VE, we calculated the Spearman correlation between 'Hallucinatory Experience' and 'Reality Judgment' as well as between 'Hallucinatory Experience' and 'Experienced Bizarreness' for both conditions. All analyses were performed using SPSS 25 (IBM, 2018) and RStudio version 1.2.5033 (RStudio, Inc., 2019) with R version 3.6.2 (R Core Team, 2019), the statistical significance level was set to $\alpha = 0.05$, and effect sizes were reported as Cohen's d for paired t-tests, r for Wilcoxon signed rank tests, and partial squared eta η^2_{part} for ANCOVAs. Finally, we compared experience ratings during REM sleep dream with those during BizarreVR qualitatively. We used the mean values of those seven items asking for experienced bizarreness, which we adapted from the Subjective Experiences Rating Scale (SERS, Kahan & LaBerge, 2011). Comparison was between the bizarreness ratings reported in their study and bizarreness ratings from our study. Item polarization was switched for ratings from Kahan and LaBerge (2011), such that higher values indicate more bizarreness.

3. Results

3.1. Evaluation of the BizarreVR paradigm

The values for Reality Judgment and Experienced Bizarreness are shown in Table 2. Reality Judgment differed significantly between the two conditions (RealisticVR vs. BizarreVR, $t(38) = 10.048$, $p < .001$, $d = 1.60$), with higher values in RealisticVR than in BizarreVR (Fig. 4, left). Further, Experienced Bizarreness was significantly higher in BizarreVR compared to RealisticVR ($t(38) = -16.603$, $p < .001$, $d = 2.646$, Fig. 4, right).

The relationship between Reality Judgment and Experienced Bizarreness was computed by means of a linear mixed model. The model to predict Reality Judgment with Experienced Bizarreness and Condition, and Participant as random effect, showed a substantial total explanatory power (conditional $R^2 = 0.76$, marginal $R^2 = 0.52$). Within this model, the effect of Experienced Bizarreness was significant and negative (Fig. 5), with beta = -1.06, the 95% CI of $[-1.87, -0.25]$, and $t(72) = -2.57$, $p = .013$. There was no significant effect of Condition and no significant interaction between Experienced Bizarreness and Condition in the model. The model's intercept, corresponding to Condition = 'RealisticVR' and Experienced Bizarreness = 0, is at 9.71 (95% CI of $[8.08, 11.34]$, $t(72) = 11.68$, $p < .001$). This indicates that Reality Judgement can be predicted from the values of Experienced Bizarreness independent of Condition with a strong negative correlation.

Regarding spatial presence, descriptive values are presented in Table 2. Self Location did not differ significantly between the two conditions ($t(38) = -1.884$, $p = .067$, $d = 0.309$, Fig. 6, left), but showed a trend for higher values in BizarreVR than in RealisticVR (Table 2). Unexpectedly, Suspension of Disbelief differed significantly between conditions ($t(38) = 2.040$, $p = .048$, $d = 0.331$), with higher values in RealisticVR compared to BizarreVR (Fig. 6, right).

As well, the control variable 'VR Sickness' was significantly different between conditions ($Z = -2.152$, $p = .031$, $r = 0.345$), with higher values in RealisticVR compared to the BizarreVR (Table 2). To control for the confounding factors 'Effect of Order' and 'VR Sickness', we added the factor 'StartCondition' as a between-subjects factor and 'VR Sickness' as a covariate to our analyses. The difference for experience of reality between conditions remained significant for both Reality Judgment ($F(1,36) = 4.986$, $p = .032$, $\eta^2_{part} = 0.122$) and Experienced Bizarreness ($F(1,36) = 16.024$, $p < .001$, $\eta^2_{part} = 0.308$). Further, the difference between conditions in Self Location was still not significant and became smaller ($F(1,36) = 1.412$, $p = .242$, $\eta^2_{part} = 0.038$). The difference in Suspension of

Table 2
Means and standard deviations for all dependent variables in the two VR conditions.

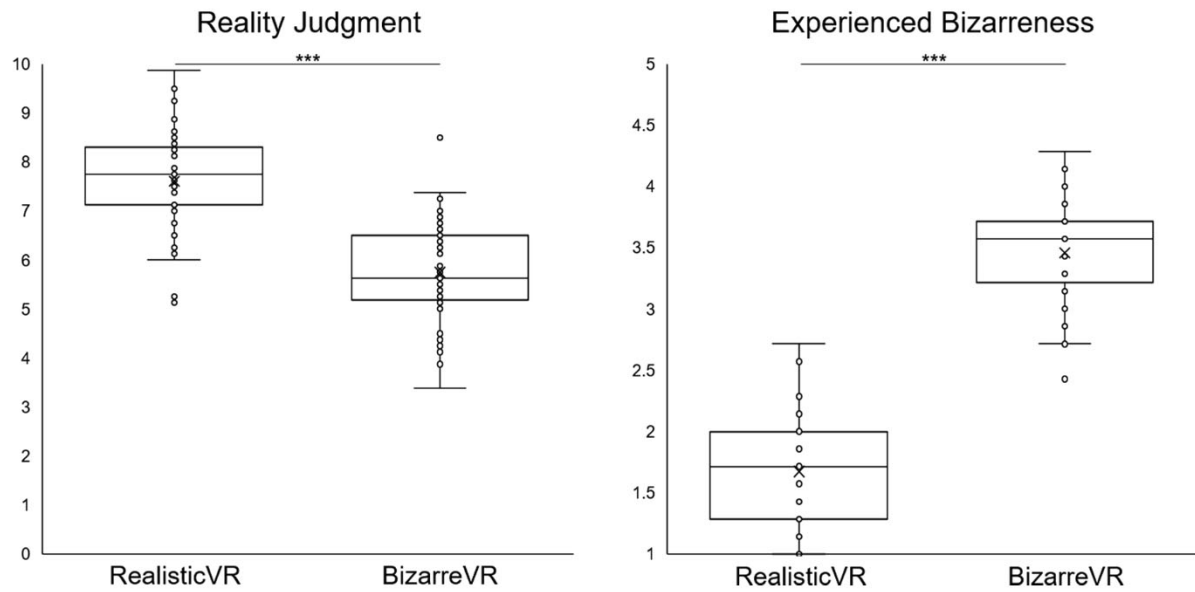|	RealisticVR		BizarreVR	
	M	*SD*	*M*	*SD*
Reality Judgement	7.61	1.06	5.75	1.08
Experienced Bizarreness	1.98	0.34	3.37	0.37
Self Location	3.94	0.67	4.10	0.56
Suspension of Disbelief	2.78	0.93	2.51	0.76
VR Sickness	1.67	0.39	1.57	0.39

Fig. 4. Influence of Condition on conscious experience of reality. Boxplots and individual scores of 'Reality Judgement' (left, Likert scale range 0 to 10) and 'Experienced Bizarreness' (right, Likert scale range 1 to 5) between conditions (RealisticVR vs. BizarreVR). The boxes indicate the 25–75 percentile of the distribution; whiskers represent the non-outlier range. Horizontal bars within the boxes indicate median values; the crosses indicate mean values. ***p < .001.
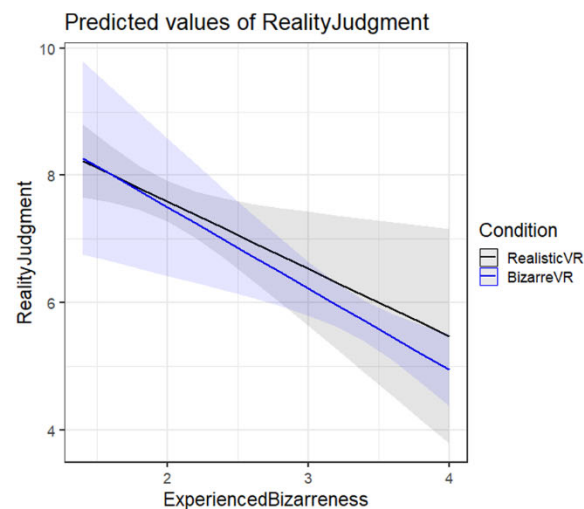

Fig. 5. Predicted values of Reality Judgment by Experienced Bizarreness for the two conditions. The model to predict Reality Judgment included Experienced Bizarreness and Condition as fixed effect, and Participant as a random effect.

Disbelief between conditions became non-significant and smaller as well ($F(1,36) = 1.214, p = .278, \eta^2_{part} = 0.033$). This indicates that after considering confounding factors the paradigm successfully induced differences in experience of reality between conditions and that presenting bizarre elements in the BizarreVR had no systematic influence on spatial presence.

3.2. Relationship between experience in VR and general hallucinatory experience

When looking at individual proneness towards hallucinatory experience, we found a rather low mean score relative to the LSHS sum score range of 0–48 ($M = 9.54, SD = 5.64$, range 2–27). However, compared to a representative sample ($M = 7.0, SD = 6.9$; Lincoln et al. 2009), our mean value was even slightly higher. Moreover, Hallucinatory Experience and Reality Judgment were positively correlated in the BizarreVR condition ($r_s = 0.3267, p = .042$), such that higher values on the hallucinatory experiences scale were associated with higher values for experience of reality while experiencing dream-like bizarre elements. Hallucinatory Experience was neither correlated with Reality Judgment in the RealisticVR condition nor with Experienced Bizarreness in both conditions.
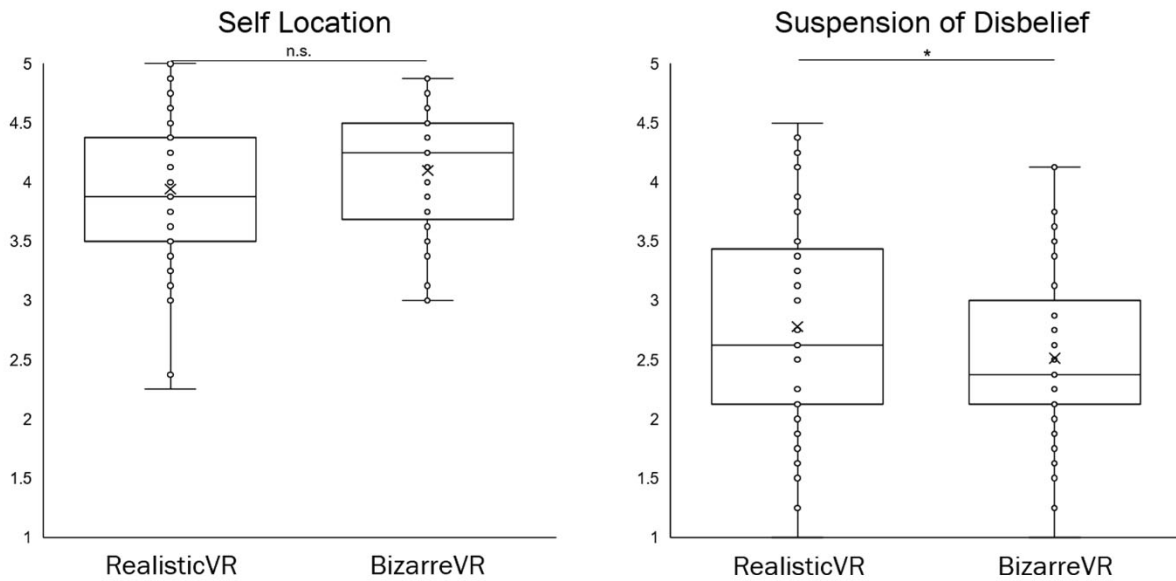
Fig. 6. Influence of Condition on conscious experience of spatial presence. Boxplots and individual scores of 'Self Location' (left) and 'Suspension of Disbelief' (right) between conditions (RealisticVR vs BizarreVR). The boxes indicate the 25–75 percentile of the distribution; whiskers represent the non-outlier range. Horizontal bars within the boxes indicate median values; the crosses indicate mean values. *p < .050, n.s. = non-significant.

3.3. Comparison of experienced bizarreness with previous data from REM dreams

Mean values of the compared items are depicted in Fig. 7. Ratings for Experienced Bizarreness in BizarreVR were more similar to REM sleep dream ratings than to ratings during wake. BizarreVR was rated slightly more bizarre than REM sleep dreams with regard to location and transitions. Moreover, ratings for Experienced Bizarreness in RealisticVR were more similar to ratings during wake than to those during REM sleep dream.

4. Discussion

4.1. Summary of the main findings

The present study examined the effect of dream-like bizarre breaks in a highly immersive and naturalistic VE on conscious
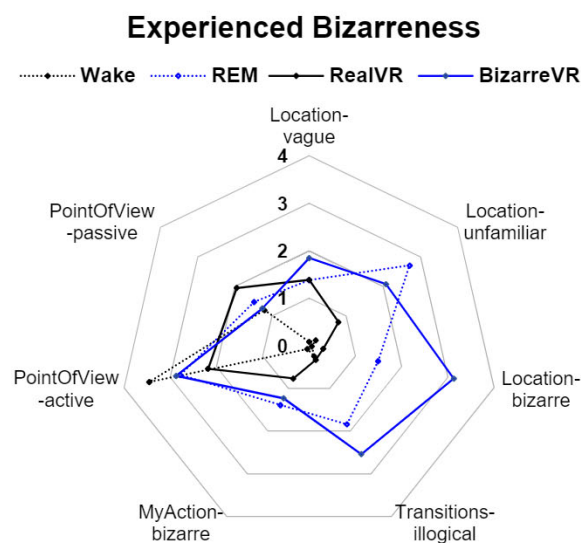

Fig. 7. Qualitative comparison of Experienced Bizarreness ratings during BizarreVR and RealisticVR with ratings assessed during wake and REM sleep dreaming by Kahan & LaBerge (2011). Spider web rows represent values of the rating scale; mean item values are plotted as dots.

experience of reality in the normal waking state. Experience of bizarreness was successfully induced by dream-like bizarre elements presented in the highly immersive VE. Interestingly, when comparing our experience ratings with those reported in Kahan and LaBerge (2011), experienced bizarreness ratings during BizarreVR appeared more similar to dream experience ratings during REM sleep than to ratings during wake. Moreover, we found high levels of reality judgment and low levels of experienced bizarreness during RealisticVR. Our results serve as a proof of concept for the new BizarreVR paradigm to induce differences in experience of reality and bizarreness.

As hypothesized, being confronted with bizarre breaks in an otherwise realistic VE reduced participants' reality judgment and increased their experienced bizarreness. This negative relationship between Reality Judgment and Experienced Bizarreness was confirmed independent of condition, i.e. with or without the presence of bizarre elements. Thus, we could show that processing bizarre breaks in a dream-like scenario while being in the normal waking state leads to a decrease in experience of reality.

Further, spatial presence in terms of self location was not reduced by bizarre breaks occurring in the objects and place of the VE. After controlling for confounding variables, bizarre elements did not interfere with self location and suspension of disbelief.

We also found individual differences in experience. In the dream-like bizarre VE, participants with higher tendency towards hallucinatory experience judged the bizarre environment as more real, indicated by a significant positive correlation between reality judgment and hallucinatory experience in the BizarreVR condition.

4.2. Bizarre breaks and reality judgment in the theoretical framework

To obtain a potential mechanistic explanation for the effect of bizarre breaks on experience of reality, we discuss our findings within the framework of predictive processing. We assumed that bizarre breaks in the normal wake state elicit prediction errors at highest levels of the hierarchical generative model, since bizarre breaks are processed at higher-level cortical areas related to meta-cognition. If unresolved by new predictions or new sensory input, these errors would lead to increased bizarreness experience and decreased reality judgment. The finding of increased bizarreness ratings and decreased reality ratings in the BizarreVR condition supports our assumption. A possible interpretation is that bizarre and unexpected breaks in an otherwise realistic context elicit a prediction error by violating the highest-level predictions. If no new prediction can be drawn from prior knowledge to resolve the error, this may lead to reduced reality judgment. Bizarre breaks potentially reached highest levels of the model, because the validity of the bizarre sensory signal was high due to high accuracy of the sensorimotor feedback provided by the immersive VR setup. At the same time, a valid but bizarre sensory input creates an ambiguity between prediction error and valid input, which cannot be solved by sampling new sensory input (it maintains valid but bizarre), and thus leads to an increase in experienced bizarreness. Moreover, bizarre breaks occurring in the place and objects of the VE did not affect spatial presence. Spatial presence can be explained by the suppression of prediction errors at lower somatosensory levels of the model due to highly accurate sensorimotor feedback mediated by our technical setup. This indicates that bizarre breaks in the VE elicited prediction errors at higher levels of the hierarchical generative model rather than at lower somatosensory levels. Further, these higher-level errors were not involved in creating the VR illusion as measured by spatial presence.

4.3. Reality judgment during wake vs. sleep

The finding that reality judgment was significantly decreased after experiencing bizarre breaks during the normal wake state is similar to the findings by Drori et al. (2020), where hallucination-like deviations in VR lead to significantly reduced reality ratings. However, this is opposite to what usually happens during dreaming, where reality judgment is usually not decreased by bizarre breaks. During dreaming, it is still unclear, whether prediction errors as a result of bizarre breaks do not reach highest levels of the hierarchical model due to aberrant error processing or whether no prediction errors occur at all due to lacking precision of the non-existent sensory input. Interestingly, after training for lucid dreaming, the presence of bizarre breaks can induce a questioning of the current reality, which can then lead to the judgment about the experience being a dream and not real, i.e. a lucid dream (Gott et al., 2021). The difference between non-lucid and lucid dreams is, amongst others, a stronger activation of brain areas like the Precuneus (Baird et al., 2019), which has been shown to be involved in self-reflection and other metacognitive functions (Cavanna & Trimble, 2006). Deactivation of the Precuneus in the normal wake state has been suggested to induce the feeling of being in a dream or a parallel world (cf. Siclari et al., 2017). Potentially, this kind of metacognition or meta-consciousness needs to be intact to evaluate the reality of an experience adequately and is a potential explanation why reality judgment fails during non-lucid dreaming when confronted with bizarre breaks.

4.4. Reality judgment and hallucinatory experience

The results of this study also contribute to the discussion about hallucinatory experience in the general population (Van Os et al., 2009). First, we found some variance in hallucinatory experience in our sample of young and healthy participants comparable to a representative sample by Lincoln et al. (2009). Moreover, with higher tendency towards hallucinatory experience, the bizarre environment was judged as more real. Thus, the variance in hallucinatory experience was mirrored in the ratings of experienced reality in the bizarre environment. However, since we did not find the same relationship for the realistic environment or for experienced bizarreness, we must be careful when generalizing this finding. Further, our mean sum score on the LSHS scale was slightly higher compared to the general population reported by Lincoln et al. (2009), but still lower than the mean sum score in their patient population. This can be explained by the finding that young age is associated with higher values on the LSHS scale (Larøi et al., 2019) and our sample is notably younger than the one of Lincoln et al. (2009).

4.5. Bizarre breaks and spatial presence

The finding that bizarre breaks did not affect spatial presence contribute to an ongoing debate about whether the plausibility of the experience has an influence on spatial presence (cf. Hofer et al., 2020). We manipulated the degree of plausibility using dream-like bizarre breaks in the place and objects of the VE and found no effect on spatial presence in terms of self location and suspension of disbelief after controlling for confounding variables. This supports the idea of spatial presence being a lower-level process and experience of reality and bizarreness as manipulated in our experiment being a higher-level process. Likewise, participants' knowledge about wearing a VR HMD did not interfere with their feeling that the current experienced scene actually happened, as indicated by high values for self location. This would again be in line with the dual system approach discussed by Hofer et al. (2020). They discussed spatial presence as being a lower-order cognitive process (a cognitive "feeling") and plausibility judgement, which refers to reality judgment in our terms, as being a higher-order cognitive process. It is also comparable with the idea of a meta-consciousness as introduced by Frith (2021), in which reality judgement can be seen as a higher-order process of consciousness, similar to metacognition.

4.6. Possible applications

Our paradigm has proven suitable for the investigation of experience of reality in a scenario with very few confounding factors. It also enables the investigation of virtual reality experience parameters such as presence. In combination with other physiological measures such as heart rate, skin conductance, or electroencephalography, it will be possible to investigate in more detail the underlying physiological mechanism of experience of reality and its relationship with presence in VR. Moreover, with this paradigm a potential effect of bizarre experience on subsequent dreams could be investigated as well. An interesting question for the research on dream content would be whether the bizarre elements experienced in VR are transparent to the subsequent dream. It may also be interesting to investigate the potential influence of individual differences in dream bizarreness on the effect of dream-like bizarre elements in VR on experience of reality. Additionally, to investigate the differences in experience of reality between the normal wake state and psychopathology, other populations such as patients diagnosed with schizophrenia or other psychotic diseases could be tested within this paradigm. Such additional data would allow the investigation of the interaction between psychotic experience (yes vs no) and bizarre elements (present vs absent).

4.7. Limitations and future experiments

Using immersive VR, a highly realistic scenario can be created. However, this realistic experience is not completely like experiencing something as real. Thus, the experiences in our paradigm are only similar to dreams but not exactly like dreams. In dreams, people do not know, that they are dreaming, while in immersive VR, participants always know, at least on a higher-level, that the experience does not correspond to reality. Nevertheless, the ratings for presence and reality judgment in our paradigm were high relative to the scale limits, so it still holds that the experience in the BizarreVR is to a high degree similar to reality.

The paradigm is well suited for investigating a global state of bizarre experience. However, we did not intend to question participants on a trial-by-trial basis throughout their VR experience in order not to break their VR illusion. A trial-based assessment with the BizarreVR paradigm would require a passive way to assess reality judgment. As well, to obtain the required number of trials, more than six dream-like bizarre 3D objects need to be created. An advantage of a trial-based assessment would be that it allows for a more detailed investigation of prediction error processing. For example, whether the error is suppressed rather by lowering the precision of the sensory input or by lowering the precision of the prediction. A potential investigation might look at how participants behave after seeing each bizarre break. An eye or body movement might possibly indicate an action or a change of attentional focus due to a prediction error to generate new sensory input because the old input's precision was low.

5. Conclusion

We successfully evaluated a new paradigm to induce systematic differences in conscious experience of reality using dream-like bizarre elements in immersive virtual reality. Dream bizarre elements induced experience of bizarreness and reduced experience of reality. Moreover, we found that experience of reality was explained by experience of bizarreness independent of condition. We interpret these results within the theoretical framework. Further, inducing experience of bizarreness and unreality did not interfere with spatial presence, the "feeling of being there" in the virtual world, such that spatial presence was high and similar in both conditions. This suggests that the sense of spatial presence is distinct from a sense of reality and these two kinds of experience seem to be explained by a dual systems theory, in which the two processes do not interfere. Additionally, since we specifically chose dream-like bizarre elements as implausible breaks within the VE, we were able to compare bizarre dream-like experience with non-bizarre wake-like experiences systematically unconfounded by different physiological states. Thus, with our paradigm, we contribute a new tool to the investigation of conscious experience of reality. Future projects may use the paradigm to measure physiological correlates of conscious experience of reality.

CRediT authorship contribution statement

Simone Denzer: Conceptualization, Methodology, Software, Validation, Investigation, Formal analysis, Data curation, Writing –

original draft, Writing – review & editing, Visualization. **Sarah Diezig:** Conceptualization, Writing – review & editing. **Peter Achermann:** Supervision, Writing – review & editing. **Thomas Koenig:** Conceptualization, Methodology, Formal analysis, Writing – review & editing, Supervision, Funding acquisition. **Fred W. Mast:** Conceptualization, Methodology, Resources, Writing – review & editing, Supervision, Project administration, Funding acquisition.

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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.concog.2022.103283.

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