A Comparative Study Examining the Effects of Mixed and Virtual Reality on Plausibility Illusion and Emotional States

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Research Report

A Comparative Study Examining the Effects of Mixed and Virtual Reality on Plausibility Illusion and Emotional States

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Abstract: Understanding the unique impact of extended reality (XR) technologies, such as virtual reality (VR) and mixed reality (MR), on emotional states is important for predicting users' subsequent judgments and behaviors. Nevertheless, it remains unclear whether and how the differences in the structural affordances of VR and MR (i.e., a sense of being there vs. a sense of an object being in the physical environment) can indeed induce distinct effects. Therefore, the present study aims to elucidate the role of VR and MR technologies on users' emotional states through the theoretical lens of plausibility illusion. Specifically, we hypothesized that plausibility illusion would mediate the effects of XR modality on emotional states, including arousal and perceived fear toward a fearful object. In addition, we explored the potential moderating role of object virtuality (i.e., ontological characteristic of virtual objects) in the relationship between XR modality and plausibility illusion. Results from a mixed 2 (XR modality: VR vs. MR) × 2 (virtuality: para-authentic vs. artificial) design experiment (N = 100) showed that VR induced a higher sense of plausibility illusion than MR, which played a mediating role in amplifying arousal and perceived fear. This finding suggests that the differences in the structural affordances of VR and MR can induce distinctive effects on emotional states. Further implications of the findings are discussed.

Keywords: mixed reality, virtual reality, virtuality, plausibility illusion, emotional states

In recent years, Extended Reality (XR) technologies, such as Virtual Reality (VR) and Mixed Reality (MR), have become increasingly integrated into our daily lives (Ball et al., 2021). As defined by Palmas and Klinker (2020), VR is "a computer-generated virtual environment that allows users to interact with, move around in, and be completely immersed in a virtual environment," while MR is "an overlay of virtual content that can interact with the actual environment" (p. 322). By the trend, research into the effects of XR on user perceptions and behaviors has started to accelerate, further broadening its possible applications to various domains such as anatomy training (Vergel et al., 2020), education (Huang et al., 2019), and exposure therapy (Tsai et al., 2018).

Despite the increased interest, it remains understudied whether and how the difference in the structural affordances of VR and MR technologies (i.e., a sense of being there vs. a sense of an object being in the actual environment; Steffen et al., 2019) will distinctively influence users' emotional states when experiencing emotionally valenced objects through either technology. Given that the intensity and valence of emotional or affective states could serve as a psychological compass that could guide people's subsequent judgments and behaviors (Bodenhausen et al., 1994), we must understand whether and how VR and MR technologies would induce distinctive effects in amplifying the intensity and valence of emotional states evoked by virtual stimuli. To fill in the knowledge gap, this study examines the differences between VR and MR in amplifying the intensity and valence of users' emotional states using the theoretical framework of plausibility illusion (Slater, 2009).

Among the various constructs under the umbrella of emotion, the current study particularly focuses on examining the effects of VR and MR on emotional arousal (i.e., the intensity of emotion; Syrjämäki et al., 2022) and perceived fear towards a fearful object (i.e., negative valence). This is

because arousal and fear have been often found to be influenced by the major affordance of immersive technologies (i.e., a sense of presence; Diemer et al., 2015). Additionally, we explore the possible moderating role of virtuality (i.e., para-authenticity vs. artificiality), which was originally introduced to explicate the concept of presence (i.e., a psychological state in which virtual objects are experienced as actual objects in either sensory or nonsensory ways) in virtual environments (Lee, 2004a). We argue that this concept is relevant for explaining users' experiences of virtual stimuli in VR and MR.

Presence Theory

The term "(tele)presence" was originally introduced by Minsky (1980) to describe the phenomenon wherein operators felt as if they were transported to a distant location while using teleoperating systems. Previous scholars have made various attempts to clarify the concept of presence based on a common understanding that presence denotes the experience of realism in response to psychological immersion and is a subjective experience of "being there" in a virtual environment (Slater & Wilbur, 1997). More specifically, presence is commonly understood as a fundamental human experience that occurs when individuals perceive themselves to be transported to a virtual or mediated environment where they are not physically present (Heeter, 1992; Steuer, 1992; Witmer & Singer, 1998). In simpler terms, Reeves (1991) defined presence as a sense of "being there."

However, previous conceptualizations have faced criticism for being too specific to particular media, limiting their applicability across various technological domains and constraining the scope of presence research. Consequently, Lee (2004a) redefined presence as "a psychological state in which the virtuality of experience is unnoticed" (p. 65). Later, Jerome and Jordan (2007) defined the concept as "the degree to which one believes that he or she exists within a mediated space" (p. 78), which occurs when the mediated space closely resembles non-mediated (real) environments in physical reality.

Despite extensive efforts to broaden the applicability of the definition across various technological domains, it has recently been argued that presence may still not be the ideal concept for comparing the distinct effects of VR and MR technologies on user perceptions (Latoschik & Wienrich, 2022). This is primarily due to the failure of presence to conceptually capture the differences in the structural affordances between VR and MR technologies. Although VR and MR are often grouped together in predicting perceptual outcomes by mass media and literature, the structural affordances of the two technologies are fundamentally different.

Functionally, while VR enables the transportation of users to computer-generated virtual environments, creating a sense of presence (Huang et al., 2019), MR overlays digital content onto the user's real-world surroundings, effectively enhancing the physical environment with virtual objects (Milgram & Kishino, 1994). These unique characteristics can give rise to a distinct perception of realism and immersion, with VR fostering a sense of being there in a different environment, while MR generates the impression of virtual objects integrated within the actual environment (Steffen et al., 2019). For this reason, the concept of the plausibility illusion (Skarbez, 2016; Slater, 2009) has started to gain interest from scholars as an alternative construct for comparing the two different XR technologies.

Plausibility Illusion as a Key Construct

As mentioned above, in the context of MR, the concept of presence has limited applicability, as users maintain a more direct connection with their physical surroundings and the real-world environment while interacting with virtual objects (Latoschik & Wienrich, 2022). Accordingly, scholars have suggested the concept of *plausibility illusion* as a subcomponent of presence to facilitate a fair comparison between VR and MR modalities (Latoschik & Wienrich, 2022). This concept provides a more suitable framework for comparing the extent to which users assess the perceived realism of VR and MR experiences.

Among various definitions of presence explicated by Skarbez (2016), Slater (2009) defined place illusion and plausibility illusion as the two sub-constructs of presence. The vital difference between place illusion and plausibility illusion lies in the feelings of "being there" versus "what is apparently happening is really happening" (p. 3553). Recent developments, however, have suggested that both sub-constructs are not equally applicable to different modalities of XR. For example, Latoschik and Wienrich (2022) have advocated for the construct of plausibility illusion as a better premise for comparing experiences in XR than place illusion. This is because place illusion focuses on the feelings of "being there," which may not be as relevant to MR or "lower" immersive technologies within the Reality-Virtuality Continuum (Milgram & Kishino, 1994), where the user is not necessarily transported into a virtual environment. Slater (2009) also demonstrated that the concept of plausibility illusion is equally relevant to both VR and MR. This suggests that plausibility illusion could enable a fair comparison between the effects of VR and MR on the intensity and valence of emotional states by playing the role of a mediator. Nevertheless, despite the newfound proposition, there is still a lack of empirical research applying plausibility illusion as a means to compare the efficacy between XR modalities.

Importantly, Skarbez (2016) proposed the concept of coherence, an objective quality of a system, as the counterpart to the subjective experience of plausibility illusion.

Skarbez (2016) defined a virtual scenario as coherent when it "behaves in a reasonable and predictable way" (p. 44). Specifically, coherence is the extent to which the virtual environment and the objects within it demonstrate reasonable circumstances without introducing unreasonable circumstances. The difference between coherence and the subjective experience of plausibility illusion lies in whether or not the circumstances in a virtual scenario are congruent with prior knowledge.

Latoschik and Wienrich (2022) have further explained that plausibility within XR experiences hinges on the integration of sensory, perceptual, and cognitive aspects. This suggests that sensory stimuli (e.g., visual and aural cues) encountered within XR environments are typically processed at both perceptual and cognitive levels. During the processing of these sensory stimuli, social-cognitive factors, including users' prior knowledge and experiences, could influence the evaluation of coherence. Given the notion, the plausibility illusion is likely shaped by the XR experience, which includes sensory stimuli, and the utilization of these stimuli as cues to assess coherence, drawing from prior knowledge and worldviews. At the heart of this perspective lies the fundamental role of coherence and the plausibility of sensory cues in eliciting the sense of the plausibility illusion in XR environments (Latoschik & Wienrich, 2022).

Notably, Skarbez (2016) conducted an experiment to investigate the impact of varying levels of coherence on the sense of plausibility illusion. This study suggested that the sense of plausibility illusion increases as individuals evaluate the coherency of the attributes in the virtual environment that induce the plausibility illusion, including the (1) virtual body, (2) virtual scenario, (3) physical interaction, and (4) virtual human behavior (Skarbez et al., 2021). Among these factors, this research demonstrated that the coherence in the appearance and behavior of real and virtual bodies is the primary factor contributing to the sense of plausibility illusion, followed by the coherence of virtual scenarios (i.e., users assess the coherence of virtual scenarios by comparing it with prior knowledge and determining its appropriateness with the objects). Skarbez (2016) argued that an accurate representation of the virtual body is extremely powerful for convincing a user that "This is real" (p. 96). The distinct structural characteristics of VR and MR technologies in visualizing the virtual bodies of users introduce the possibility that the use of a real body (i.e., a real hand) for virtual interaction in the MR setting could determine the extent to which users experience the sense of the plausibility illusion. Based on these findings, the present study predicts that MR may induce a higher sense of plausibility illusion than VR due to the reduced disparity between real and virtual bodies:

Hypothesis 1 (H1): Exposure to a virtual object in MR will result in a higher level of plausibility illusion than exposure to the same virtual object in VR.

The Potential Moderating Role of Virtuality: Para-Authenticity Versus Artificiality

In an attempt to taxonomize the various motivations for virtualization, Steffen et al. (2019) proposed a framework of XR affordances. One affordance in the framework emphasizes the use of XR to experience things that are not possible in the real world, either due to non-existence or time-space constraints. This affordance is congruent with the definition of virtual experience explicated by Lee (2004a): "the experience of either para-authentic or artificial objects" (p. 36). Lee (2004a) defined the para-authenticity of an object as the mediated version of an actual counterpart that exists in the real world (e.g., a digital cat). In contrast, an artificial object is defined as a simulated object that does not have a physical counterpart in the real world (e.g., a digital unicorn). This dichotomy of virtuality is rarely investigated in the context of XR, despite it being proposed as one of the many affordances of the technology.

Worthy of note, the virtuality of a virtual object may affect the extent to which users experience the sense of plausibility illusion. Skarbez (2016) found that one crucial factor affecting the sense of plausibility illusion is the coherence of the scenario, which users assess by comparing it with prior knowledge and determining its appropriateness with the objects. When the concept of scenario coherence is combined with the definition of the artificiality of an object (Lee, 2004a), it can be inferred that artificial objects would generally induce a lower sense of plausibility illusion due to a lack of prior knowledge. As artificial objects do not exist in the real world, users may not have a reference point to deem whether the virtual object is correct and predictable. Moreover, there is no reference point for an appropriate context for the artificial object to be deemed coherent and plausible. Additionally, as MR overlays the artificial object above the real environment (Craig, 2013), participants might perceive it as less plausible because the artificial object does not exist in real life (Lee, 2004a). Thus, MR may induce a higher sense of plausibility illusion when experiencing para-authentic, rather than artificial, objects.

Furthermore, Steffen et al. (2019) proposed a framework for VR and AR affordances and suggested that their ability to enact affordances can be influenced by physical context and sensory vividness. They argued that MR or AR would be the preferred method of virtualization for experiences

that need to entail the context of a real environment. Meanwhile, VR would be the preferred method of virtualization for experiences that do not require the context of a real environment. When considering the notion of artificial and para-authentic objects (Lee, 2004a), it is likely that experiencing an artificial object without a real counterpart in VR would induce a higher sense of plausibility illusion. Conversely, an artificial object in MR might be perceived as less plausible than in VR due to incoherence with the real environment. Based on this idea, we propose the following hypothesis:

Hypothesis 2 (H2): The virtuality of an object (para-authentic vs. artificial) will moderate the effects of modality (VR vs. MR) on plausibility illusion, such that the effects will become stronger when an artificial object and a para-authentic object are respectively visualized via VR and MR.

Plausibility Illusion and Emotional States: Arousal and Perceived Fear

The differences in the structural affordances between VR and MR technologies suggest that the psychological mechanisms underlying the use of VR and MR may also differ. However, we are still left unknown whether and how such structural differences will indeed amplify or diminish the intensity and valence of users' emotional states. This knowledge gap arises due to the scarcity of comparative studies that examine the effects of various XR modalities.

The literature on the effects of plausibility illusion on emotional states is also scarce. However, as evidenced in the review of VR research, presence is often found to significantly heighten emotional arousal (i.e., the intensity of emotion; Syrjämäki et al., 2022) and the perception of negative emotions such as anxiety and fear (Diemer et al., 2015). In particular, most of the previous studies have consistently highlighted that fear is an emotion that could be significantly intensified through the sense of presence (Price et al., 2011; Schuemie et al., 2000). These findings suggest that plausibility illusion (i.e., a sub-construct of presence; Slater, 2009) might also enhance emotional arousal and perceived fear when encountering a fearful object in immersive experiences with either VR or MR. Based on the previous findings, we propose that plausibility illusion will be associated with emotional arousal and perceived fear of a fearful stimulus:

Hypothesis 3 (H3): A higher sense of plausibility illusion will result in a higher level of (H3a) arousal and (H3b) perceived fear towards a fearful stimulus.

Mediating Role of Plausibility Illusion

To the best of our knowledge, there is a lack of empirical evidence applying plausibility illusion as a means of comparing perceptual differences between XR modalities. Accordingly, it remains unclear whether plausibility illusion will play a significant mediating role in explaining the effects of XR modality on emotional arousal and valence. However, since VR and MR vary in their capabilities to create a coherent experience and different levels of plausibility illusion may induce varying degrees of emotional arousal and valence, we predict that plausibility illusion may serve as a mediator that explains the relationship between XR modality and emotional states. Therefore, the following hypotheses are proposed:

Hypothesis 4 (H4): Plausibility illusion will mediate the effects of XR modality on (H4a) arousal and (H4b) perceived fear.

Methods

Experiment Design

We conducted a 2 × 2 mixed factorial ANOVA laboratory experiment to validate our hypotheses, with XR modality (VR vs. MR) as the within-subjects factor and virtuality of stimuli (para-authentic vs. artificial) as the between-subjects factor (see Figure 1). XR modality was measured as a within-subjects factor to control for individual differences in experiencing different modalities (Skarbez, 2016). Participants were randomly assigned to either the para-authentic or artificial object condition and experienced the stimulus in both VR and MR, with the order of modality randomly assigned and balanced across participants to control for possible order effects.

Participants

A total of 101 people participated in the experiment, with 36 males (35.64%), 64 females (63.37%), and one non-binary participant (0.99%). The average age of participants was 22.11 years (SD = 3.16), ranging from 18 to 30 years. We removed one participant due to straightlining behavior and analyzed 100 samples. According to the results of a priori power analysis conducted using G*Power version 3.1.9.7 (Faul et al., 2007), our study's sample size exceeded the minimum required for a 2 × 2 mixed factorial ANOVA design when set at 80% power for detecting a medium effect (i.e., f = .25) at an α level of .05 (i.e., N = 34).

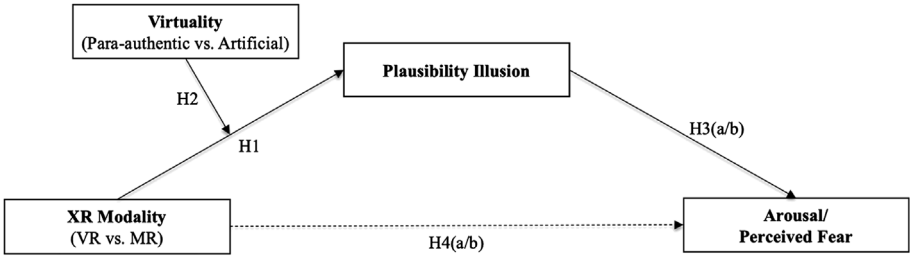

Figure 1. Research model. The dashed line indicates a mediation path.

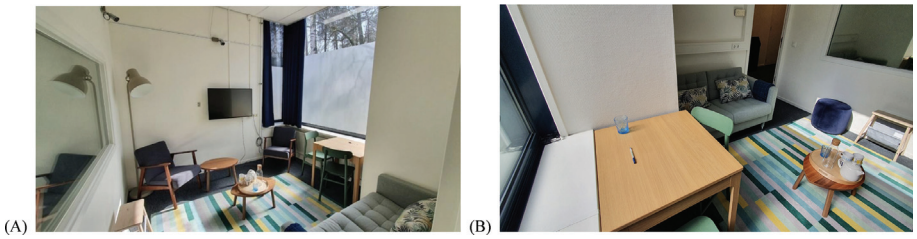

Figure 2. Living room environment in the MR condition.

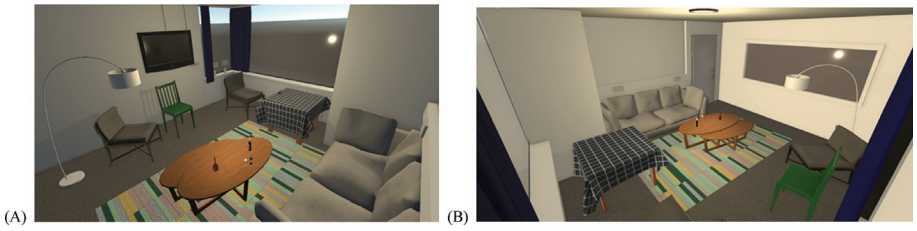

Figure 3. Living room environment in the VR condition.

The data was collected over 4 weeks at a university in Western Europe, and the study was approved by the university's Research Ethics and Data Management Committee. Participants were recruited through the university participant pool, and those with arachnophobia or extreme fear of arachnids were excluded from the study to prevent unwanted psychophysiological reactions.

Equipment and Stimuli

Participants in the MR condition used a Microsoft HoloLens 2 to interact with the stimulus in a living room environment, while those in the VR condition used an HTC Vive Pro with a controller in a virtual living room environment. In both conditions, participants were seated on a chair with a table in front of them where the stimulus was located (see Figures 2 and 3).

An arachnid tarantula object downloaded from the Unity Asset Store (Unity Technologies, 2023) was selected as the para-authentic stimulus (see Figure 4A) to induce fear responses based on the study of Hauke and Herzig (2017). A relatively large spider was used to ensure comparable size to that of the artificial stimulus and avoid size as a confounding factor (Lee, 2004b). The artificial stimulus chosen was "King Scorpion," a fantasy arachnid creature with glowing green eyes (see Figure 4B), to establish control between stimuli. Both stimuli had similar looped movements lasting about 25 s to avoid motion as a confounding factor (Reeves et al., 1985).

Procedures

The participants were asked to come to the experimental laboratory and sign the consent form. Then, they were seated in either the living room (i.e., MR condition) or an empty room (i.e., VR condition) and were briefed on how to interact with the virtual object. They were given 1.5 min to observe and interact with the virtual object, with the time predetermined through a preliminary test. To ensure that participants paid close attention to the stimulus, they were instructed to observe the stimulus closely, as there would be questions about the stimulus at the end of the study.

After 1.5 min of the first exposure, the participants completed the first half of the survey. They were then asked to move to another room and experience the same stimulus but in another modality. After the second exposure, they completed the remainder of the survey. At the end of the

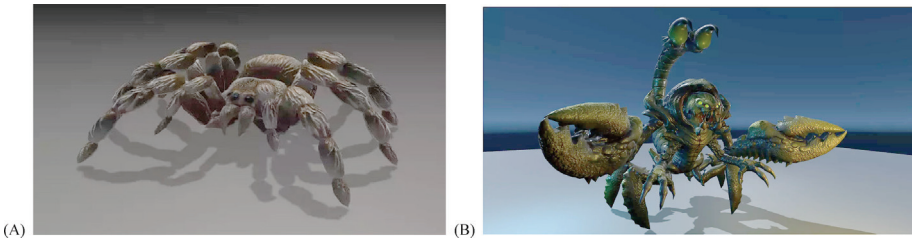

Figure 4. Virtual stimuli. (A) Para-authentic object: Tarantula; (B) Artificial object: King scorpion.

survey, participants were debriefed and given 1.0-course credit in exchange for their participation.

Measures

Plausibility Illusion

To measure plausibility illusion, two 7-point Likert scale items were adapted from the virtual human plausibility scale developed by Mal et al. (2022): The two items were "The appearance of the animal seemed plausible to me as if the creature is real" and "The appearance of the animal seemed to match well with the appearance of animals in our reality, as if the creature is real." Since the measure had only two items within the construct, Spearman-Brown coefficients were calculated to assess the internal consistency reliability of the measure. The internal consistency reliability was acceptable (VR condition: α = .73; MR condition: α = .86; Overall: α = .81).

Arousal

To measure the intensity of emotional response to the stimulus, we used the effective slider (Betella & Verschure, 2016). The effective slider measures arousal by presenting a facial expression at each end of the slider. The slider collects data on a continuous scale ranging from −100 to +100, with the starting point of the slider located at the middle of the scale (i.e., 0 value).

Perceived Fear

Perceived fear was measured using three 7-point Likert scale items ranging from *very low* to *very high* adapted from the study of Lin et al. (2017) (e.g., "The degree of fear I felt was…"). The internal consistency reliability was acceptable (VR condition: α = .88; MR condition: α = .84; Overall: α = .86).

Manipulation Check

To ensure that the perceived fear of the para-authentic and artificial stimuli are similar, a 7-point Likert scale item (i.e., "The stimulus I was exposed to was scary"; 1 = *not at all* to 7 = *very much*) was asked. In addition, we also checked the manipulation of virtuality using a 7-point semantic differential scale ("The stimulus I was exposed to was..."; 1 = *para-authentic* to 7 = *artificial*). Results showed no significant difference in fear response between the tarantula (M = 2.76, SD = 1.64) and the imaginary creature (M = 2.82, SD = 1.73), M_{diff} = −0.06, $t(98)$ = −0.18, p = .86, d = −0.04. The virtuality manipulation was also successful, with significantly higher scores for the artificial object (M = 4.06, SD = 1.61) than the para-authentic object (M = 2.42, SD = 1.77) on the semantic differential scale, M_{diff} = −1.64, $t(98)$ = −4.84, p < .001, d = −0.97.

Data Analysis

Statistical analysis was conducted using the mediation moderation for repeated-measures (MEMORE) macro developed by Montoya and Hayes (2017). Model 1 was used to test for H1, H3(a/b), and H4(a/b), while Model 2 was used to test for H2.

Results

Hypotheses Testing

Hypothesis 1 predicted that MR would induce a higher sense of plausibility illusion than VR. Inconsistent with H1, the results suggested that virtual objects experienced in VR (M = 4.61, SD = 1.39) rather induced a greater sense of plausibility illusion than in MR (M = 4.00, SD = 1.59), B = −0.61, SE = 0.14, p < .001, 95% CI [−0.89, −0.33]. Thus, H1 was not supported.

Hypothesis 2 posited that the virtuality of the object would moderate the relationship between modality and plausibility illusion. Inconsistent with our prediction, the result was statistically insignificant (B = −0.42, SE = 0.28, p = .14, R^2 = .02, 95% CI [−0.98, 0.14]), indicating that H2 was not supported. The moderation pattern is visualized in Figure 5.

Hypothesis 3 predicted that a higher sense of plausibility illusion will result in higher (a) arousal and (b) perceived fear. As predicted, results showed that a higher sense of plausibility illusion resulted in a higher level of arousal (B = 9.70, SE = 2.08, p < .001, 95% CI [5.57, 13.82]) and perceived fear (B = 0.28, SE = 0.06, p < .001, 95% CI [0.16, 0.41]). Thus, H3(a/b) was supported by the data.

Last, Hypothesis 4 posited that plausibility illusion will mediate the relationship between (a) modality and arousal,

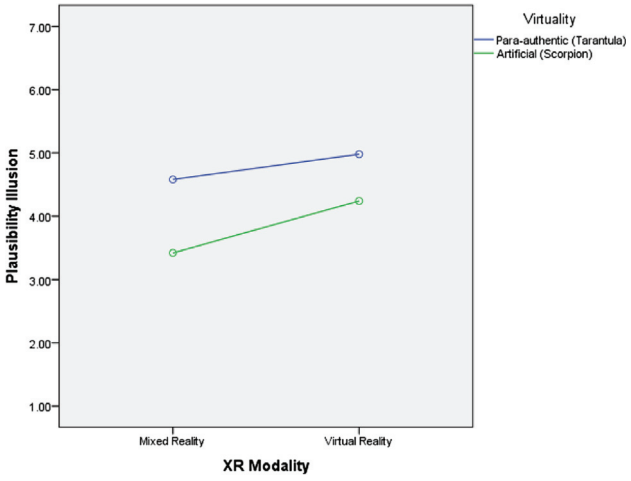

Figure 5. Moderating effects of virtuality.

and (b) modality and perceived fear. Consistent with our prediction, the results indicated that plausibility illusion significantly mediated the effects of XR modality on arousal ($B = -5.92$, $SE = 2.43$, $p < .001$, $R^2 = .21$, BCa 95% CI [−12.14, −2.32]) and perceived fear ($B = -0.17$, $SE = 0.07$, $p < .001$, $R^2 = .17$, BCa 95% CI [−0.34, −0.06]). Results were in support of H4(a/b).

The summary of results is presented in Figures 6 and 7, and the descriptive statistics of plausibility illusion across different XR modalities and object virtuality are provided in Table 1.

Discussion

Inconsistent with our prediction, the results revealed that VR induced a higher sense of plausibility illusion than MR. One possible explanation for this outcome is that users may have allocated less attention to the stimuli in MR due to the greater visual discrepancy between the virtual object and the real environment, despite the supposed realism of the MR stimuli. Skarbez (2016) has demonstrated that attention allocation is a prerequisite for experiencing the plausibility illusion, and reduced attention to the virtual stimuli in MR may have diminished the sense of plausibility illusion. Worthy of note, the reason users might have allocated fewer attentional resources to the MR stimuli could be related to the lower technical specifications of the HoloLens 2 used in the MR condition.

Although the current study made efforts to control for experimental settings related to the structural affordances of VR and MR, it is important to acknowledge that we could not account for the differences in the technical specifications between HTC Vive Pro and Microsoft HoloLens 2. More specifically, it is possible that variations in resolution (Vive Pro: 1,440 × 1,600 pixels per eye; HoloLens 2: 1,440 × 936 pixels per eye), field of view (Vive Pro: 110°; HoloLens 2: 43° horizontal), refresh rate (Vive Pro: 90 Hz; HoloLens 2: 60 Hz), and the sensitivity to the lighting conditions in a room (for HoloLens 2) between the two devices might have affected the results of our study. In other words, a higher technical specification of HTC Vive Pro as compared to HoloLens 2 might have affected the finding in relation to the effects of XR modality on plausibility illusion.

Notably, the recently released products, such as Meta Quest 3 and Apple Vision Pro, are capable of supporting both VR and MR experiences within a single device. While the current study had to use two different products to compare the effects of VR and MR modalities, since Meta Quest 3 and Apple Vision Pro were not available for use at the time of data collection, it is expected that these devices would allow for the execution of a more valid experiment by controlling for different technical specifications inherent in using different products. Therefore, future research endeavors should explore whether the findings of our study remain the same with the newly introduced XR technologies. Potentially, exploring whether the number of attentional resources allocated to the same stimuli visualized either via VR or MR within the same controlled device differs based on perceived affordance would provide deeper insights into the distinctive roles of VR and MR on user perceptions.

Additionally, this study did not find significant moderating effects of object virtuality on the relationship between XR modality and plausibility illusion. However, the moderation plot suggested an interesting pattern, which aligns with our original prediction regarding the moderating role of object virtuality on the effect of XR modality on plausibility illusion (see Figure 5). Given the moderation pattern, we suggest that future researchers further explore the potential moderating role of object virtuality on the effects of XR modality on plausibility illusion. Confirming that MR could make artificial objects perceived as less plausible than VR at statistical significance could have implications for designing future XR content by determining the most suitable immersive technology for presenting various types of virtual objects. For instance, in the domain of education, such a validation could suggest the use of VR, rather than MR, for conveying information about artificial objects or experiences that do not exist or are unseeable in our real lives.

In addition, this study found a significant effect of plausibility illusion on arousal and perceived fear. These results are in line with previous findings in which presence significantly amplified arousal and perceived fear (Diemer et al., 2015). Based on the finding future studies could investigate whether plausibility illusion may mediate the effects of XR modality on other types of negative emotions such as anxiety and disgust, as well as positive emotions such as joy

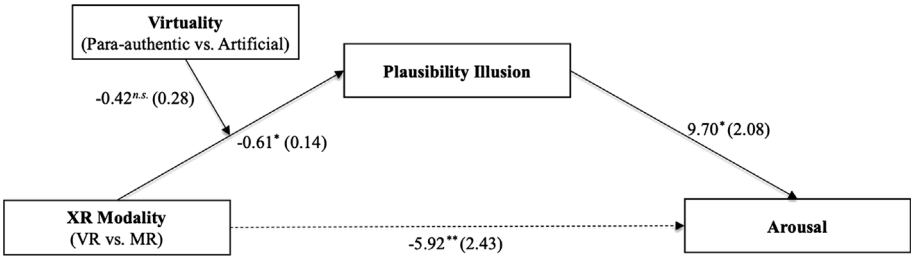

Figure 6. MEMORE results for arousal. The dashed line indicates a mediation path and unstandardized coefficients are reported. *p < .05; **p < .01; *ns* = Not significant.

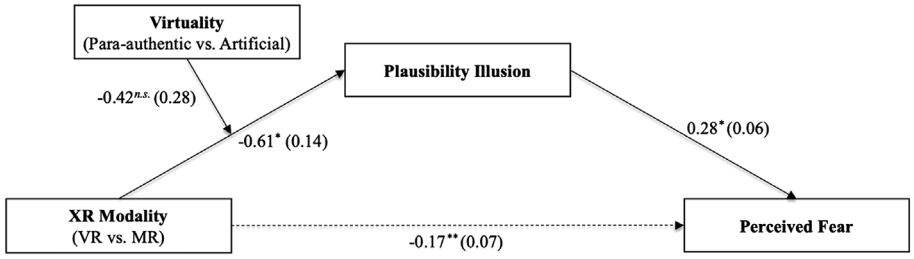

Figure 7. MEMORE results for perceived fear. The dashed line indicates a mediation path and unstandardized coefficients are reported. *p < .05; **p < .01; *ns* = Not significant.

Table 1. Descriptive statistics of plausibility illusion across XR modality and virtuality conditions

	Para-authentic object (Tarantula)	Artificial object (King Scorpion)
VR	*M* = 4.98, *SD* = 1.34	*M* = 4.24, *SD* = 1.35
MR	*M* = 4.58, *SD* = 1.52	*M* = 3.42, *SD* = 1.46

and relaxation. The findings could also guide future research on complex cognitive processes, where arousal and perceived fear impacted by plausibility illusion could influence subsequent judgments and behaviors.

As predicted, our study found a significant mediating role of plausibility illusion in the relationship between XR modality and emotional states. This finding suggests that plausibility illusion could be a useful construct for explaining how VR and MR can induce distinct effects on perceptual outcomes. As the field of plausibility illusion research is still young, we believe that our findings could be a foundation for future research. However, it is worth noting that our study only used two items from the virtual human plausibility scale developed by Mal et al. (2022), due to the fact that the measure for plausibility illusion is still under development and requires further validation. Future research could consider incorporating additional coherence factors to provide a more comprehensive measure of plausibility illusion, as suggested by Skarbez (2016). Furthermore, investigating the antecedents of plausibility illusion, such as prior knowledge and attention allocation, as well as its correlation with presence, could contribute to establishing a more robust measure of plausibility illusion.

In conclusion, the strong theoretical and practical implications of our study are expected to motivate future researchers to more actively examine the psychological mechanisms underlying the use of various types of XR technologies and their effects on user perceptions and behaviors, such as learning and persuasion. We hope that our study can serve as a cornerstone in this field.

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Conflict of Interest
This manuscript has not been published elsewhere and is not under consideration for publication by another journal. We have read and understood your journal's policies, and we believe that neither the manuscript nor the study violates any of these. There are no conflicts of interest to declare. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of Tilburg University.

Publication Ethics
Informed consent was obtained from all participants included in the study. All procedures in studies involving human participants were performed in accordance with the ethical standards of Tilburg University's Ethics Review Board (REDC 2022.17).

Authorship
Mincheol Shin: Conceptualization; supervision; writing – original draft; writing – review and editing; formal analysis; Rumittar Sibuea: Conceptualization; writing – original draft; formal analysis; Heejae Lee: Conceptualization; writing – review and editing; software – software development.

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