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The Role of Plausibility in the Experience of Spatial Presence in Virtual Environments

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In the present study, we examine the effect of plausibility violations in a virtual environment (VE) on spatial presence. After reviewing research on the association between plausibility and spatial presence, we present a dual-systems approach to understanding the effect of plausibility (or violations thereof) on spatial presence. We conceptualize the feeling of being present in a VE as a lower-order cognitive process. Perceptions of plausibility violations might represent higher-order cognitive processes that could interfere with spatial presence. We present data from an experimental study in which we manipulated the external consistency (i.e., the plausibility) of the VE, cognitive load (to interfere with higher-order cognitive processes), and immersion to examine its effect on spatial presence. Results show that immersion was the most important factor driving the presence experience. We found no difference between low and high plausibility in spatial presence. Subsequent equivalence tests showed that the group exposed to the implausible VE did not feel less present than the group exposed to the plausible VE. We discuss the findings of our studies in light of our theoretical considerations and previous research.

Keywords: spatial presence, plausibility, virtual environment, immersion, cognitive load, dual-process model

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INTRODUCTION

The present paper examines the influence of the perceived plausibility of a virtual environment (VE) on users' experience of spatial presence. There is growing consensus in the literature that spatial presence, or users' sense of "being there" in a VE, represents a cognitive feeling (Schubert, 2009) or a perceptual illusion (Slater, 2009) that strongly hinges on the sensorimotor contingencies supported by the VE (Cummings and Bailenson, 2015). Based on a meta-analysis of 85 empirical studies, Cummings and Bailenson (2015, p. 272) found that particular technological factors such as "levels of user-tracking, the use of stereoscopic visuals, and wider fields of view of visual displays" contribute to the sensation of spatial presence. Whereas these findings suggest that spatial presence might be an automatically triggered sensation that is primarily determined by the technological features of the VE, scholars have otherwise proposed that higher-order cognitive user processes might also play a role in the formation of spatial presence (e.g., higher-order cognitive involvement; Wirth et al., 2007).

Users potentially engage in higher-order cognitive operations in order to judge the credibility/plausibility (Rovira et al., 2009; Slater, 2009; Skarbez, 2016) or perceived realism of the VE (Baños et al., 2000; Schubert et al., 2001; McGloin et al., 2011). These subjective judgments, in turn, might affect how users respond to the VE, including their experience of spatial presence. For example, Slater (2009) proposed that spatial presence (addressed as "place illusion" or the "sensation of being in a real place", p. 3549) and plausibility ("the overall credibility of the scenario being depicted in comparison with expectations", p. 3549) are two orthogonal user experiences. That is, the two experiences are conceptually different and both shape the extent to which users behave realistically in a VE. Others suggest that plausibility, alternatively interpreted as the consistency of a virtual scene (Riecke et al., 2005; Skarbez, 2016), authenticity (Gilbert, 2017), or the overall perceived realism of a VE (e.g., Schubert et al., 2001; Shafer et al., 2011; Welch et al., 1996; Lombard and Ditton, 1997), might also directly affect a user's spatial presence experience.

The present approach contributes to the debate about how perceived plausibility might shape users' spatial presence experiences. More specifically, we echo the idea previously expressed by Slater (2009) that plausibility and spatial presence are two conceptually separate concepts. However, adapting a psychological dual-system logic, according to which human beings process information in two distinct brain systems (e.g., Evans and Stanovich, 2013), we interpret both concepts as conceptually separate yet causally linked. We argue that spatial presence represents a cognitive feeling (Schubert, 2009) resulting from highly automatic processing (often referred to as system 1 processing, e.g., Hartmann, 2011, 2013), whereas perceived plausibility represents an outcome of (more deliberate) higher-order cognitive processing (often referred to as system 2 processing, e.g., Hartmann, 2011, 2013). Furthermore, we propose that the perception of plausibility is a contributing, yet not necessary, factor of spatial presence. That is, users might feel spatially present in a VE because of system 1 processing without ever engaging in higher-order cognitive plausibility operations; however, once they do engage in these system 2 operations, their resulting plausibility judgment might modulate their feeling of spatial presence in a top-down fashion. Accordingly, in the present approach, we inspect how users' feeling of spatial presence differ depending on the (perceived) plausibility of the VE.

To our knowledge, although several studies provided important preliminary evidence on how users' plausibility perceptions might affect their feeling of spatial presence (e.g., Welch et al., 1996; Slater et al., 2009; McGloin et al., 2011), to date no rigorous experimental study has tested this link. Therefore, with the present approach, we aim to extend previous theoretical and empirical research that already linked perceived plausibility (or perceived realism) to spatial presence. The present approach features an experimental study. Participants navigated through a virtual house with objects (e.g., furniture) being arranged either in a plausible or implausible way in order to manipulate how plausible or realistic users would find the environment. Using self-reports, we assessed how this manipulation affected users' feeling of being spatially present in the virtual environment.

In the remainder of the present paper, we first review the different conceptualizations of plausibility in communication research. Next, we discuss research on the effects of plausibility (or the lack thereof) on presence. Based on dual-process theories (e.g., Evans and Stanovich, 2013), we then outline our rationale about how to theoretically grasp plausibility assessments and their relationship to the experience of spatial presence. Finally, we present data from an experimental study and discuss the results in light of our theoretical rationale.

PLAUSIBILITY IN PRESENCE RESEARCH

According to Skarbez (2016), the plausibility of a virtual environment is closely tied to its consistency and the extent it meets user's expectations. More specifically, Skarbez argues that virtual environments appear plausible to the extent they feature "state of affairs [...] that [are] self-evident given prior knowledge" (p. 7). Users' prior knowledge entails (a) what they know about the real world, as well as (b) what they know about the (potentially fictional) world featured by the virtual environment. Accordingly, two types of plausibility can be distinguished, as "the story world may be unlike the actual world or the story may be incoherent" (Busselle and Bilandzic, 2008, p. 267). These two types of plausibility can be termed internal and external plausibility. Both types of plausibility have been discussed in the literature in different disciplines and various research domains. Importantly, both types of plausibility represent important dimensions of users' perceived realism (for overviews, see Popova, 2010; Hall, 2017).

Internal plausibility (also addressed as internal realism, Popova, 2010, or narrative realism, Busselle and Bilandzic, 2008) refers to the extent to which the environment is consistent within itself or with respect to the expectations raised by its genre. For example, a science fiction environment might appear internally plausible if it consistently portrays a certain alien race to be able to fly, or if users first learn they are able to fly themselves, and the environment continues to allow users to fly unless providing a strong (narrative) argument against it. According to Busselle and Bilandzic (2008), internal realism is violated if new information in a story contradicts already presented information. For instance, imagine a character in a story who is introduced as a vegetarian. It would be internally inconsistent (or incoherent) if this character would eat a cheeseburger in a later scene unless his or her transition from vegetarian to carnivore is explained somewhere in between. In terms of the example outlined above, if a user of a VE was not informed that her avatar or other characters were able to fly, internal realism of the VR would be violated if flying aliens appear or the avatar lifts off into flight.

External plausibility (also addressed as probability, Popova, 2010, or external realism, Busselle and Bilandzic, 2008) refers to how consistent the virtual environment is to users' real-world knowledge. Essentially, external plausibility refers to the general question of whether something portrayed in a mediated message—from spoken statements to movies, TV news, and virtual environments—could occur in the real world (Hall, 2017). External plausibility converges with Lombard and Ditton's (1997) notion of social realism, defined as "the extent to which a media portrayal is plausible or 'true to life' in that it reflects events that do or could occur in the non-mediated world." A virtual environment is externally plausible if it features, according to the subjective notion of users, realistic settings (e.g., an authentic display of a living room, a house, or a city like Paris) and behavior (e.g., expectable functionality of displayed objects, such as being able to open a door and look through a window). External plausibility is expressed in users' global judgment that, "this is realistic or authentic." More specifically, it can be expressed in users' judgment that something is factually true or accurate (Popova, 2010). However, if users are uncertain about the factual existence of displayed locations or people, external plausibility can also be expressed in judgments that things in the environment appear to be highly likely, probable, or typical in the real world (Busselle and Greenberg, 2000; Shapiro and Chock, 2003).

In the present study, we focus on external plausibility. We do this for three reasons: (1) Whereas internal plausibility deals with the coherence of a story or the mediated world (e.g., a vegetarian does not eat cheeseburgers), external plausibility judgments arise from a comparison between the fictional or mediated world with the real or unmediated world. Therefore, one might argue that external plausibility represents a more generic type of the two. (2) Looking at research on the effects of plausibility (see below) on spatial presence we find that most studies have examined some form of external plausibility. Thus, in order to continue this line of research, we also focus on this form of plausibility (violations). Finally, (3) in order to experimentally test the effect of plausibility (or violations thereof) on spatial presence, examining the effect of external plausibility allows for a more straightforward experimental manipulation than studying the effect of internal plausibility.

The Impact of External Plausibility on Spatial Presence

Previous research provided tentative and partly mixed evidence that users' perceptions of external plausibility or realism might affect their sense of spatial presence. A first group of studies provides correlational evidence for a link between users' sense of external plausibility or realism and spatial presence. Shafer et al. (2011) conducted two experiments to illuminate the effects of interactivity on video game experience. In this context (and independent from their actual experimental test), they observed a (sometimes) strong positive correlation between users' perceived realism and their sense of spatial presence. However, their assessment of perceived realism included more dimensions (e.g., identity, utility, and perceptual fidelity) than just external plausibility—and possibly these other dimensions triggered the observed association with spatial presence. Similarly, McGloin et al. (2011) found that participants' perceptions of a video game's realism (graphics and sound) were positively correlated with their sense of feeling spatially present in the game. Other types of correlational studies focus on the development of self-report scales of spatial presence. These studies suggest an association between perceived realism and spatial presence by interpreting perceived realism as a (sub) dimension of spatial presence based on factor-analytic examinations. For example, the popular Igroup presence questionnaire (IPQ, Schubert et al., 2001) builds on the logic (and empirical observation) that perceived realism and spatial presence are positively associated. That is, both the perceived realism and the feeling of being spatially present in a mediated environment constitute the presence experience. Similarly, the Temple Presence Inventory (Lombard et al., 2009) builds on the idea that perceived realism and spatial presence are positively related.

A second group of studies reports the direct effects of experimentally manipulated plausibility or realism on spatial presence. Two studies reported by Welch et al. (1996) showed that driving a car in a "high realism" version of a virtual environment (e.g., featuring a blue sky, hilly road surface and surround, or oncoming cars) results in higher spatial presence as compared to the "low realism" version (e.g., featuring black sky, a flat surface and surrounding, and no oncoming cars). However, in both reported studies, the effect of realism on presence, if compared to the other factors examined (e.g., interactivity and response-time lag), was rather small. The authors, accordingly, concluded that, "it is not surprising perhaps that pictorial realism appeared to have little effect on presence since it would seem likely that even a completely unfamiliar environment (e.g., a room filled with random dots) could produce a strong sense of presence" (p. 270). Another experimental study by Regenbrecht and Schubert (2002) returned a small effect of perceived plausibility on spatial presence; however, results were not statistically significant. In this study, plausibility was manipulated as the perceived ability to interact with characters in a virtual environment. Notably, although the researchers manipulated perceived plausibility by telling some participants they could interact with virtual environment characters, participants were unable to actually interact with other characters. This may have contributed to the reported weak findings.

In another experiment (Krcmar et al., 2011), participants played either *Doom 1* or *Doom 3* as a manipulation of video game realism. Participants perceived *Doom 3* as more realistic and reported a stronger spatial presence experience than participants that were playing *Doom 1*. Ivory and (Ivory and Kalyanaraman, 2007) obtained similar results in a closely related experiment. However, while both studies suggest an impact of perceived realism on presence, comparing older vs. more recent titles of a video game series might also introduce potential confounds such a greater pace or smoother gameplay of the newer game that might plausibly affect spatial presence. Another experiment by Bouchard et al. (2012) circumvented this problem by manipulating subjective realism despite applying a single VR scenario, a room featuring a mouse in a cage. In the experimental condition, participants were "led to believe that they were connected in real time with [the room as] a remote location that was digitized live" (p. 229), whereas in the control condition, participants thought they were exposed to a virtual copy of the room. As compared to the control condition, participants reported significantly stronger spatial presence in the experimental condition.

A third set of studies examined plausibility violations in research on breaks in presence. Breaks in presence (BIP) occur when users stop responding to the mediated environment and instead start responding to their real (i.e., the unmediated) environment (Slater and Steed, 2000). Liebold et al. (2016) consider BIPs as "instances where the user is distracted from the VE by external stimuli or where predictions derived from the user's mental models are inconsistent with the actual outcome in the VE" (p. 480). Brogni et al. (2003) observed that more BIPs result in lower spatial presence, whereas a study by Spagnolli and Gamberini (2002) suggests that technical anomalies in a mediated environment do not necessarily lead to BIPs, but that users try to integrate these anomalies into their experience.

However, in a qualitative study, Garau et al. (2008) confronted participants four times with a technical anomaly (a screen whiteout) while navigating a VE. Results suggest that these technical anomalies lead to BIPs. Based on focus group and survey results, Liebold et al. (2016) point to more subtle factors triggering BIPs, such as invisible walls, bad co-player behavior in a video game, or floating objects in a room. In contrast to technical anomalies or interface problems, these content-related factors are more akin to what Skarbez et al. (2017) refer to as coherence of the VR and the present notion of perceived realism or external plausibility. Finally, a study by Sjoelie et al. (2014) examined the effect of expectation violations that are "related to a mismatch between your subjective mental reality and the virtual reality" on brain activity and behavior in a VR environment. These expectation violations, which can be interpreted as plausibility (i.e., external plausibility) violations, led to increased activation of brain regions that have been associated with decision-making in uncertain or ill-structured situations. The authors interpret this increase with a re-evaluation of a given situation due to expectation violations. In addition, the authors report decreased movement within the VR during plausibility violations.

In sum, there seem to be three groups of studies that deal with the effects of (or the associations between) plausibility violations and the sense of presence. However, looking at each group, we find mixed correlational evidence, different notions of realism across studies, and different methodological approaches. Thus, we still need further (theoretical) insight into whether external plausibility (i.e., perceived realism) affects spatial presence.

The Current Approach: Presence vs. Plausibility From a Dual-System Approach

In the present approach, we interpret users' sensation of being spatially present as well as their perception of plausibility (or perceived realism) within a psychological dual-system information processing approach (for related ideas, see Hartmann, 2011, 2012; Shapiro and Kim, 2012; Krcmar and Eden, 2017). This perspective builds on the psychological notion that reasoning can take place in two distinct brain systems, one system triggering intuitions, another one enabling reflections and deliberation. More specifically, "intuition (system 1) is fast and automatic, giving rise to feelings of confidence [...] but with no conscious knowledge of the basis of these feelings. Reflective processing (system 2) is slower, involving manipulation of representations through working memory [...]. However, reflective processing does not necessarily override or correct faulty intuitions" (Evans and Stanovich, 2013, p. 18). Departing from the initial focus on reasoning, scholars in psychology also related the dual-processing logic to other domains such as emotions and, more closely related to the present approach, perception (Kahneman, 2003).

It is commonly assumed that presence results from effectively provided sensorimotor contingencies, based on the immersive capacities of the underlying media technology (Cummings and Bailenson, 2015). Schubert (2009) proposed to conceptualize presence as a cognitive feeling, i.e., "a feedback from unconscious cognitive processes that informs conscious thought about the state of the spatial cognitive system" (p. 161). Following these notions, we consider presence an output of fast and effortless system 1 processing that is either closely tied to (Kahneman, 2003) or includes perceptual information (Herschbach, 2015). We conceptualize spatial presence as the intuition or gut feeling of users of being physically located in a mediated environment. As a quickly arising gut feeling within system 1, presence might strongly depend on sensory input from the underling media technology that feeds into hard-wired or heavily trained laws of spatial perception (Cummings and Bailenson, 2015).

However, users' cognitive elaborations of the environment might also affect presence (e.g., Wirth et al., 2007; Hofer et al., 2012). In the present approach, we consider related higher-order cognitive elaborations as representing system 2 processing. That is, they are cognitively more taxing (drawing on working memory and causing cognitive load) and they are slower than the perceptual processes initially triggering presence. Plausibility operations can be conceptualized as typical higher-order cognitive activity or system 2 processing. They require a certain effort and attention, and might be interrupted by secondary tasks. We conceptualize plausibility assessments as higher-order cognitive processes because in plausibility operations, users must cognitively represent the environment and compare this representation to what they know about the real world (external consistency) or scrutinize it for internal inconsistencies (Popova, 2010). Because human beings are cognitive misers, they only engage in system 2 processing, including plausibility operations, when necessary (as in default-interventionist dual-process models; Evans and Stanovich, 2013). One typical case is if system 1 processing faces perceptual problems, as in encounters of unfamiliar or puzzling stimuli, that might require further cognitive elaboration in order to be solved (e.g., Weber and Wirth, 2014).

In line with this notion, we expect users to engage in system 2 plausibility operations if they encounter virtual scenes that appear unfamiliar or puzzling (i.e., not plausible). The outcome of the operation is a judgment on the environment's plausibility. Once this "perceived plausibility" has been defined, it might intervene in or revise the outcomes of system 1 processing. While the intervention potential of system 2 processing on system 1 processing has been shown with respect to correcting intuitions (Evans and Stanovich, 2013) or regulating emotions (Gross, 2001), the ability to correct system 1 outcomes linked to more perceptual sensations like optical illusions is more contested. Many scholars agree that optical illusions (like seeing two lines of different length in the famous Mueller-Lyer illusion), for example, are cognitively impenetrable (Kahneman, 2013). "No amount of insight derived from education or experience can free us from optical illusions" (Tryon, 2014, p. 144).

However, the perceptual experience of spatial presence in VE, and the cognitive feelings underlying this illusion, might resemble a more complex system 1 output than the simple perception of line length like in the Mueller-Lyer illusion. Accordingly, presence might not be determined by "hard-wired" automatic perceptual processes, but might be partly penetrable by top-down cognitive influences, including plausibility judgments. In light of the current debate, the power of plausibility judgments to affect the cognitive feeling of presence clearly deserves further empirical scrutiny. Accordingly, in the current study, we manipulated the external plausibility of a virtual environment and tested effects of this plausibility manipulation on feelings of spatial presence.

THE CURRENT STUDY

The overarching question of the present paper is whether plausibility as a system 2 process can influence spatial presence as a system 1 impression/feeling. Our core hypothesis, thus, is that presence is lower if users perceive a virtual environment as implausible as compared to a plausible version of the same environment (H1). In this study, we are also testing two potential moderators of this effect. First, if plausibility really builds on a system 2 process, pondering plausibility and regulating system 1 processes based on plausibility might be cognitively taxing. An individual user's ability to devote cognition to plausibility judgments is not infinite, however, and may be limited by cognitive load. Hence, the effectiveness of regulating system 1 processes, like the sensation of presence, based on system 2 plausibility judgments might be reduced if the cognitive system is already under load due to other tasks (see Krcmar and Eden, 2017, for similar reasoning). Accordingly, the proposed regulating effect of plausibility on presence should be diminished if users are under cognitive load (H2).

Second, the stronger the presence illusion, the harder it might be to break it. Hence, the ability of plausibility to regulate presence might also depend on the intensity of presence as a system 1 output, which hinges—as a hard-wired automatic process—strongly on the immersive quality of the input. For example, perceived implausibility might reduce the sensation of being present in a mental imagery space, as when readers are transported into the story world of a book (Busselle and Bilandzic, 2008), but the regulating effect of perceived implausibility might be diminished if users experience intense perceptual illusions of presence (e.g., triggered by immersive technology like VR). In general, the regulating effect of plausibility on presence might be diminished for highly immersive spatial environments (that trigger more intense spatial presence) as compared to less immersive environments (that trigger less intense spatial presence) (H3). We put these three hypotheses to test in a lab experiment.

METHOD

The experimental study employed a 2 (plausibility of environment: high vs. low) × 2 (immersion of environment: high/head-mounted display vs. low/screen-only) × 2 (cognitive load: high vs. low) between-subjects design. A total of 195 undergraduate students at a large Midwestern university participated in the study ($n_{female} = 118$, $M_{age} = 21.14$, $SD_{age} = 6.86$) and were randomly assigned to conditions. The study was approved by an institutional review board.

Procedure

Participants were greeted by the research assistant and given an informed consent form. After signing the form, participants received an explanation of the study procedure. They were told that they would play a video game in which they should walk through a virtual house. After that, participants were randomly assigned to either sit in front of a 23 inch monitor ($n = 93$) or to be equipped with an Oculus Rift DK2® head mounted display (HMD; $n = 102$). Following that, the research assistant started the simulation and told the participant that they would have a short practice session of 1 min to familiarize themselves with the game controls (i.e., the mouse and the arrow keys, which were used by all participants to move around within the computer simulation). After this practice session, within the computer-generated environment participants were automatically transferred to the second floor of the virtual house. They were told that they could freely explore the environment for 4 min. Then, the research assistant left the room. After 5 min, the assistant came back and told the participants to take off the HMD and the headphones and open the browser window with the questionnaire assessing the dependent variables. Finally, participants were debriefed and dismissed.

Stimulus

We used a computer simulation of a house with two floors. The simulation was programmed with the Unity Game Engine (Version 5.5.0f3). The first floor consists of an entrance area that leads to a living room/kitchen area. The second floor consists of a bathroom with a bathtub, a bedroom with a bed and a dressing table with a chair, a children's room with a crib, and an office room with an office table and a home trainer. The plausibility and the cognitive load factors were manipulated within the stimulus.

Plausibility was manipulated in terms of the notion of external consistency (Skarbez, 2016). More precisely, we manipulated the physical behavior of objects and the appearance of the environment: In the implausible condition (**Figure 1**, left; $n = 96$), the bathroom sink, bathtub, and toilet were upside down. In the bedroom, the bed, the dressing table, and the chair rotated continuously and were attached to the wall instead of standing on the floor. The objects in the children's room spontaneously shrunk and enlarged, snow fell in the office room and the floor seemed to be made of running water. Participants in the group with high plausibility (**Figure 1**, right; $n = 99$) walked through a

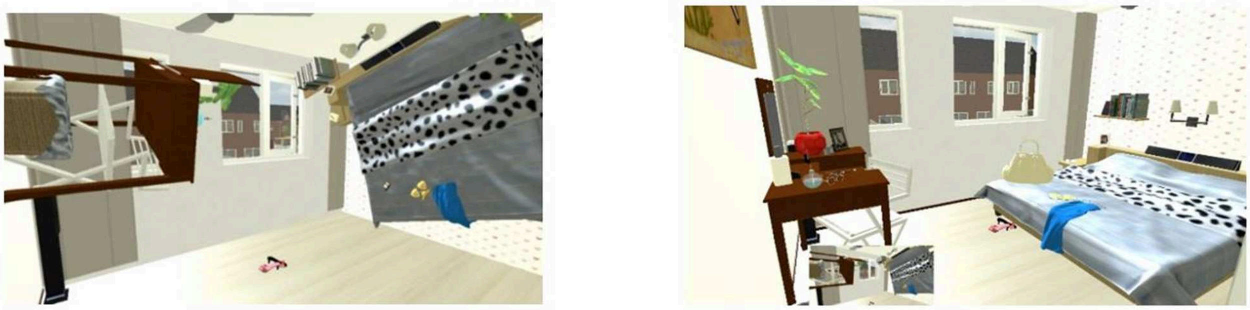

FIGURE 1 | The example images from the implausible (left) and plausible (right) virtual house.

house with rooms that one would expect to find in a typical house without any of the aforementioned implausible objects. The plausibility manipulation in this particular virtual environment has been validated in two previous studies. Lee et al. (2019) found that viewers ($n = 22$) looked longer (49 vs. 1 s) at objects in the implausible vs. the plausible conditions (see Lee et al., 2019, Figure 3), suggesting that the implausible environment requires more effortful processing. In a separate sample, a thematic analysis of comments made while participants ($n = 17$) walked through the house (Den Ouden, 2015) demonstrated greater frequency of comments regarding the realism of the environment in the implausible condition (54% of total comments) vs. the plausible (0.02% of total comments).

To manipulate immersion, participants either wore an Oculus Rift® (high immersion, $n = 102$) or saw the virtual house on a 23 inch TN computer monitor (low immersion, $n = 93$).

Finally, to manipulate cognitive load, we applied the Gilbert Digit Rehearsal Task (Gilbert and Hixon, 1991). Participants in the group with high cognitive load ($n = 99$) were told to memorize a nine-digit number and were shown this number for 30 s after being transferred onto the second floor of the virtual house. Participants in the group with low cognitive load ($n = 96$) were simply told to walk through the environment.

Measures

Spatial Presence. We used the eight item Spatial Presence Experience Scale (SPES, Hartmann et al., 2015) to assess spatial presence self-location using a seven-point Likert scale ranging from 1 = completely disagree to 7 = completely agree (e.g., "It seemed as though my self was present in the environment," $M = 4.40$, $SD = 1.54$, $\alpha = 0.96$). Spatial presence possible actions were also measured with the eight items version of the SPES (e.g., "I had the impression that I could act in the environment," $M = 3.87$, $SD = 1.46$, $\alpha = 0.93$).

Manipulation Check. To assess the perceived plausibility of the VR, we created three items (e.g., "The rooms I walked through are very similar to rooms in real life," $M = 4.05$, $SD = 1.73$, $\alpha = 0.84$). Participants could indicate their (dis-)agreement on a seven-point Likert scale. A principal component analysis yielded a single factor (explained variance: 76.56%, loadings ranging from .93 to 77).

RESULTS

To test the success of our plausibility manipulation, we conducted an analysis of variance (ANOVA) with the three experimental factors (i.e., plausibility, immersion, and cognitive load) as independent variables, all two-way interactions and the three-way interaction, and perceived plausibility as the dependent variable. Only the plausibility manipulation had a significant effect on perceived plausibility: $F(1, 186) = 83.61$, $p < 0.001$, $\eta^2_{part} = 0.31$. None of the other independent variables nor any interaction term had an effect on perceived plausibility (all Fs < 1).

Next, we examined the effect of the plausibility manipulation on (1) spatial presence self-location and (2) spatial presence possible actions by conducting two ANOVAs including the three experimental factors, as well as the two-way and the three-way interaction terms. As expected, the immersion manipulation (high immersion/Oculus Rift vs. low immersion/screen) had a significant effect on both spatial presence self-location [$F(1, 187) = 25.40$, $p < 0.001$, $\eta^2_{part} = 0.12$] and spatial presence possible actions [$F(1, 187) = 4.93$, $p = 0.03$, $\eta^2_{part} = 0.03$] with higher values in the high immersion/Oculus Rift condition (high immersion/Oculus Rift: $M_{self-location} = 4.98$, $SD_{self-location} = 1.56$, $M_{possibleactions} = 4.10$, $SD_{possibleactions} = 1.51$; low immersion/screen: $M_{self-location} = 3.85$, $SD_{self-location} = 1.32$, $M_{possibleactions} = 3.63$, $SD_{possibleactions} = 1.37$). There was no significant effect of the cognitive load manipulation on self-location [$F(1, 187) = 2.93$, $p = 0.08$, $\eta^2_{part} = 0.02$] or on possible actions [$F(1, 187) = 3.06$, $p = 0.08$, $\eta^2_{part} = 0.02$].

More importantly, contrary to H1, plausibility did not affect spatial presence self-location [$F(1, 187) = 0.06$, $p = 0.81$, $\eta^2_{part} = 0.00$] or spatial presence possible actions [$F(1, 187) = 0.02$, $p = 0.88$, $\eta^2_{part} = 0.00$]. We also did not observe any significant two-way interaction or three-way interaction affecting self-location or possible actions, which rejects H2 and H3.

We also conducted a Kolmogorov-Smirnoff-Test. More specifically, we tested whether we could reject the null-hypothesis that the residuals of the dependent variables in the model are normally distributed. According to this test, the residuals of spatial presence self-location are likely to be normally distributed, as the test did not show a significant result ($p = 0.200$). The test for spatial presence possible actions showed a significant result ($p = 0.049$), which indicates that the residuals are likely not to be normally distributed. Therefore, in terms of spatial presence possible action, the result of the ANOVA has to be treated with caution.

Next, to further scrutinize the null-effect regarding H1, we examined whether the means of spatial presence self-location and possible actions were indeed equal across the plausibility manipulation (Weber and Popova, 2012). More precisely, with an equivalence test, we examined whether the means for spatial presence self-location and possible actions were not (as we initially expected) smaller in the implausible VR than in the plausible VR condition. In other words, with equivalence tests the null-hypothesis can be tested. We conducted a one-tailed equivalence test, in which we set the initially expected effect size delta to 0.15, based on a meta-analysis by Cummings and Bailenson (2015). More specifically, we took the weighted effect size (r) for the immersion variable "image quality" in the study by Cummings and Bailenson (2015) because this variable is the closest to what we manipulated in our study, namely external consistency. The equivalence test was significant for spatial presence self-location [$t(193) = 0.26$, $\Delta = 0.15$, $p_{eq} = 0.04$] and for spatial presence possible actions [$t(193) = -0.07$, $\Delta = 0.15$, $p_{eq} = 0.03$]. Thus, we can conclude that the means of both dimensions of spatial presence are indeed equivalent across the two plausibility groups, again rejecting H1.

DISCUSSION

The present experiment examined the effect of plausibility violations within a virtual environment on users' sense of spatial presence. We conceptualized the experience of spatial presence in a mediated environment as a perceptual system 1 process that potentially can be affected by higher-order system 2 processes, such as plausibility assessments. Participants who were exposed to the implausible VR environment in the present study reported significantly lower levels on the perceived plausibility measure. However, this successful manipulation had no effect on either dimension of spatial presence (i.e., self-location and possible actions). Additional equivalence tests showed that the means in the group encountering an implausible VR were not smaller than the means in the group exposed to a plausible VR. Participants in the present study seemed to successfully integrate encountered anomalies into their experience, thus leaving their presence sensation untouched (see also Spagnolli and Gamberini, 2002)—or they simply did not succeed in regulating their presence experience in light of plausibility violations. From this perspective, the observed "null-effect" confirms the perspective of scholars advocating for the cognitive impenetrability of perceptual sensations (e.g., Tryon, 2014).

The experimental study also included immersion and cognitive load as experimental factors and potential moderators that have been shown to affect perceptual and higher-order cognitive processes. A substantial body of studies has provided evidence that immersion affects spatial presence (for an overview, see Cummings and Bailenson, 2015), and we expected that the presumed presence-regulating effect of implausibility on presence might be diminished if sensations of spatial presence were particularly strong, due to a highly immersive environment. Similarly, research has shown that cognitive load can affect information processing, such as attention or visual perception (Sweller, 1994), and we expected that cognitive load might interfere with the presumed presence-regulating effect of implausibility. However, none of the two related two-way interactions were significant. Accordingly, we found no evidence for these two mechanisms. This finding could imply that plausibility operations might not necessarily represent a cognitively taxing system 2 activity. To the extent this is true, it might be more fruitful to consider the interplay of plausibility operations and presence as an interplay between cognition and perception rather than two information processing systems.

In summary, the results of the present experiment thus suggest that plausibility (as we defined and manipulated it) has no impact on the sensation of presence; users seem to feel equally present in plausible or implausible virtual environments, perceived implausibility does not seem to regulate the presence sensation. As discussed in sections one and two, research on the relationship between presence and plausibility produced mixed results. For instance, correlational studies (e.g., Lombard et al., 2009; Shafer et al., 2011) repeatedly found relationships between the experience of presence and perceived plausibility, whereas experimental studies sometimes found effects (e.g., Krcmar et al., 2011) and sometimes did not (e.g., Regenbrecht and Schubert, 2002). As mentioned above, differences in both conceptualizations and operationalizations of plausibility have to be taken into account. In our study, we manipulated external plausibility and did not find an effect of this manipulation on spatial presence. Notably, the results of our study are in line with Slater's (2009) argument that place illusions (referred to as spatial presence in this manuscript) and plausibility illusions (what we would call perceived plausibility in this manuscript) are two orthogonal factors.

Nevertheless, anecdotal reports from and non-systematic observations of some of the participants suggested that some specific implausible responses of the VR might in fact reduce the sensation of spatial presence. Accordingly, perhaps in our experimental study we focused on manipulating a specific type of (im)plausibility (namely external plausibility) that does not affect presence, while other types of implausibility exist that actually may interfere with the presence experience. For example, akin to initial findings from Garau et al. (2008), one could distinguish more carefully external plausibility violations that disturb the spatial makeup of the VE (e.g., real glitches or incomprehensible spatial information) from external plausibility violations that are spatially correct (like the flipped environment displayed in the present study). The former plausibility might diminish presence, while the latter might not. However, as a caveat, the processing of other types of plausibility might not require cognitive load, hence they are unlikely candidates for system 2 processing as we proposed here. For example, spatial glitches represent a type of implausibility that directly interrupts the perceptual system 1 processing, thus weakening presence. Users might not need to engage in effortful system 2 processing to reflect on incomprehensible spatial information in order to down-regulate presence subsequently. Accordingly, although spatial glitches might be more effective in breaking presence than other external plausibility violations, they might be less suited to illuminate the present dual-system idea and logic of cognitive penetrability of spatial presence addressed in the this research.

To explore the possibility that other types of plausibility violations exist that do affect presence, future research could complement the results of the present quantitative experimental study with insights from a qualitative think-aloud study that designed to illuminate the interplay of plausibility and presence in a more fine-grained manner, similar to Den Ouden (2015). Or, similar to Lee et al. (2019), a content analytic review of participants' walk-through may reveal individual idiosyncrasies which may better explain individual responses to implausibility than examining them in the aggregate. It is worthwhile to also consider violations of internal plausibility in this context; for example, an implausible narrative might reduce users' sense of presence.

In conclusion, we found no significant difference in the experience of spatial presence between the low and high plausibility environment—and this "null effect" adds to the body of research on the associations between plausibility (violations) and the sense of being there.

On a more general level, this finding adheres with the idea that it is difficult to regulate hard-wired perceptual sensations such as presence based on top-down higher-order cognitive operations. If this general idea is correct, one might also speculate that immersive technologies like VR induce, in general, powerful perceptual sensations in users, based on hard-wired mechanisms—and these sensations might remain largely unaffected by users' more reflective thoughts (e.g., about any artificiality in the experience). In this regard, VR would differ from less immersive traditional media in which users' higher-order cognitive awareness that "this is not real" proves to be a powerful mechanism to regulate induced experiences (e.g., down-regulating suspense while watching a film). Accordingly, it remains to be seen to what extent VR users' awareness of the mediated nature of their experience (i.e., "knowing that this is not real") is still an effective mechanism in shaping their immediate sensations.

As a final note and limitation of the present study, the present sample size could be considered as rather limited given the study's experimental design (i.e., a 2 × 2 × 2). However, smaller samples are not uncommon in studies on presence in virtual environments (see Cummings and Bailenson, 2015). Also, in addition to the nil-null hypothesis significance testing, we also performed an equivalence test, which provides strong evidence for the lack of a difference between the high and the low plausibility group in terms of spatial presence.

In conclusion, we believe that our study is a valuable first step toward a better understanding of the role of plausibility in the formation of spatial presence.

DATA AVAILABILITY STATEMENT

The dataset, the questionnaire and a video example of a walkthrough of the environment can be accessed at the following link: https://dx.doi.org/10.17605/OSF.IO/TDS9C.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by a Human Research Protection Program, Office of Regulatory Affairs. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

All authors have collaborated on this manuscript. The order of the authors reflects the amount of work put into the manuscript. MH and TH: conducting of experiment, writing, and revision. AE, RR, and LH: writing, revision.

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