Computers in Human Behavior Reports 4 (2021) 100111

Contents lists available at ScienceDirect

Computers in Human Behavior Reports

journal homepage: www.journals.elsevier.com/computers-in-human-behavior-reports

The human source memory system struggles to distinguish virtual reality and reality

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ARTICLE INFO

Keywords:
Virtual reality
Memory
Source monitoring
Ecological validity
Virtual reality exposure therapy

ABSTRACT

Virtual Reality (VR) is used in a variety of fields with the goal to increase ecological validity compared to traditional monitor-based setups. Here we report additional evidence for the adequacy of this research strategy. In a memory confusion paradigm spanning over stimuli presentation in reality, VR and on a computer monitor, participants were more prone to confusing reality with VR than with a traditional monitor-based setup, indicating a relative proximity of experiences in VR and reality. We speculate that the human source memory's difficulty in distinguishing VR from reality may provide a basis for the good generalizability of treatment effects in VR to daily life. At the same time, the effect may demonstrate a potential danger of a mindless use of VR technology.

1. Introduction

Virtual Reality (VR) technology is increasingly used in a range of research fields such as the study of social interactions (Pan & Hamilton, 2018) and episodic memory (Smith, 2019) or the treatment of mental disorders (Freeman et al., 2017). In behavioral research, a typical motivation to allow participants or patients to immerse in virtual worlds is to increase ecological validity relative to more traditional laboratory setups which were frequently found to provide only limited generalizability to real-world situations (documented e.g. in the different processing of (Laidlaw et al., 2011; Rubo, Lynn, & Gamer, 2020) and different brain responses to (Cabeza et al., 2004; Chow et al., 2018; Pönkänen et al., 2010) real-life experiences compared to corresponding stimuli on a computer monitor). Similarly to experiences in every-day life, VR allows users to freely look around and inspect objects using binocular vision, typically eliciting a sense of *presence* or *being there* in the virtual world (Sanchez-Vives & Slater, 2005; Skarbez et al., 2017) and allowing the brain to act along predictive embodied simulations similarly to real-life situations (Riva et al., 2019). At the same time, VR retains the same level of experimental control known from other experimental techniques.

Findings from various fields of inquiry now support the view that experiences in VR may relatively closely resemble real-life experiences on some critical dimensions. For instance, treatments of specific phobias using exposure therapy carried out in VR were found to generalize well to real-world situations (Freeman et al., 2017; Morina et al., 2015), suggesting that fear responses may not differentiate whether habituation was learned in the real world or in VR. When directly comparing attention towards a virtual world seen in VR or on a computer monitor, Rubo and Gamer (2021) found a more pronounced gaze reactivity towards a virtual agent's social behavior when viewed in VR. Recall for the position of objects in 3-dimensional arrangements were improved when the scene was viewed using a head-mounted display compared to when it was viewed on a computer monitor (Krokos et al., 2019). It was furthermore found that place cells — neurons in the hippocampal-entorhinal circuit which are activated when occupying a specific position in space and help organize memories about specific locations (Moser, Rowland, and Moser, 2015) — can be activated in VR (although so far, this was demonstrated only in rats; Aronov & Tank, 2014; Harvey et al., 2009), but are not activated by spaces seen through videoconferencing (Li, Arleo, and Sheynikhovich 2020).

A different approach to evaluating if an artificial environment is experienced similarly to the real world was brought forward by Hoffman, Garcia-Palacios, Thomas, & Schmidt. (2001) who proposed to test — as a "sort of Turing test of how convincing the virtual world is" (p. 565) — how accurately individuals can distinguish memories which were encoded in reality from memories which were encoded in the artificial environment. This idea rests on the observation that memory traces can be accompanied by a *source tag* which allows to not only remember a certain content, but also the memory's source (e.g. the magazine in which one read about a specific fact or the person one learned it from). However, when source tags are imprecise or lacking, they may be inferred heuristically by relying on the memory trace's characteristics such as its

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https://doi.org/10.1016/j.chbr.2021.100111
Received 14 December 2020; Received in revised form 14 May 2021; Accepted 2 June 2021
Available online 9 June 2021

perceptual detail or the amount of cognitive effort required to retrieve and organize it (Johnson et al., 1993; Schacter et al., 2011). For instance, a memory trace about a real swim in the sea may be more perceptually rich and easier to retrieve compared to a similar memory trace originating from reading a story, facilitating its correct attribution as representing a real occurrence. Intriguingly, observing systematic errors in reconstructing source tags allows to retrace the shape of cognitive categories: Using the *who-said-what*-paradigm — where participants view a group discussion and are subsequently asked to attribute utterances to the correct individual — source-tag confusions occurred more frequently between speakers who belong to the same coalitional alliance (Kurzban et al., 2001) or have a similar accent (Pietraszewski & Schwartz, 2014), thus identifying and quantifying the importance of these categories in observers' (social) cognition.

Following Hoffman's et al. (2001) proposition, we used a similar *memory confusion paradigm* in the present study to investigate if experiences in VR are categorized as more *real* compared to experiences involving a computer monitor. Participants viewed a variety of animal figurines either as physical models or as computerized 3D models through a VR headset or on a computer monitor, and, analogously to studies employing the *who-said-what* paradigm, source tag confusions in subsequent source attributions were used to estimate the categorical proximity of the three modalities *Real*, *VR* and *Monitor*. Our choice to use commonplace and perceptually rich stimuli (animal figurines) was motivated by assertions that experiments using more lifelike stimuli which can seamlessly blend into naturalistic environments (as opposed to, for instance, plain geometric shapes) tend to more robustly generalize towards everyday life (Miller et al., 2019).

Secondly, we tested how participants' confidence ratings were associated with source attribution accuracy. Confidence is known to generally correlate well with accuracy in memory tasks (Wixted et al., 2015), but there is also evidence for a reduced confidence-accuracy relation under aggravating circumstances (e.g. when participants are asked to remember a face despite low face recognition ability; Grabman et al., 2019), although findings in this regard are mixed (Juslin, Winman, and Olsson 2000; Nguyen et al., 2017). We expected a lower confidence-accuracy relation in experimental conditions which were associated with higher error rates (e.g. when *Real* and *VR* were needed to be differentiated from each other compared to when *Real* and *Monitor* were needed to be differentiated from each other).

Thirdly, we investigated if an active manipulation of items influenced source memory performance. When manipulation was possible, perceptual richness was high in the *real* modality (where objects could be touched), medium in the *VR* modality (where objects were manipulated using one's hand, but mediated through a VR controller) and low in the *Monitor* modality (where manipulation was realized using the press of a button). On the one hand, the increase in perceptual detail both in the *VR* and the *Monitor* modality may be expected to increase the likelihood for erroneous attributions as being *real* memories (Johnson et al., 1993) — and more so in the *VR* modality where the increase in perceptual detail is stronger. On the other hand, as active manipulation in virtual scenarios was shown to increase precision in subsequent recalls (Jang et al., 2017; Sauzéon et al., 2015), and more so when using one's own body compared to when using an input device (Ruddle et al., 2010), it may be expected to reduce erroneous attributions as being *real* memories, and more so in the *VR* modality.

2. Materials and methods

2.1. Participants

19 participants (15 females, mean age = 22.67 years, $SD = 2.22$ years, range = 20–30 years) were tested in this study. Participants were continuously enrolled during the semester until the testing was aborted due to health concerns in the Covid-19 crisis. Participant number was therefore smaller than planned, but power was moderate due to extensive testing of all participants (Smith & Little, 2018). A sample size of N = 19 is sufficient to detect an effect of $d = 0.6$ in a Within-Subjects-Design with a Power of 80% and Alpha set to 5% in a one-sided comparison.

2.2. Apparatus and software

Presentation stimuli consisted of 30 anatomically correct animal models (www.schleich-s.com, see Fig. S1 in Supplementary Methods) which were available both as physical models (which were shown in a *Real* modality) and as 3-dimensional computer models (which were shown in a *VR* as well as a *Monitor* modality). Computer models were constructed from the physical models using a photogrammetrical approach and the Autodesk Recap software (www.autodesk.com). In all three modalities, models were placed on a table in front of the participants who were sitting on a chair (see Fig. 1). For the *VR* and *Monitor* modality, the table and the laboratory room were generally modelled in accordance with the real laboratory environment. The VR equipment consisted of an HTC Vive Pro system. The system's HMD had a resolution 2880×1600 pixels (1280×1440 per eye) and a 110° field of view. The experimental software was developed using Unity 3D (unity3d.com).

2.3. Procedure

Participants were invited to the laboratory individually, truthfully informed about the purpose of the study and completed an informed consent form. The study conformed to the principles expressed in the Declaration of Helsinki and was approved by the local ethics committee at the University of Fribourg (Ref-No. 516 R1). Participants were introduced to the memory task and were specifically asked to memorize the modality in which they saw each model. They were informed that they would be asked to attribute each model to the correct source after each testing block. Participants' source memory performance was then tested in 6 consecutive blocks in which all 30 animal models were on display in one of two modalities, and object manipulation was possible in none, one, or both modalities. Among the 12 possible configurations for experimental blocks (Real vs. Monitor, Monitor vs. VR, VR vs. Real, crossed with the possibility to interact in each modality), each participant was confronted with 6 randomly drawn blocks to keep the experiment's duration under 60 min and to avoid fatigue. For instance, in one specific block a participant may have seen 15 randomly drawn animal models in real-life (as physical models placed on a table) with the instruction not to manipulate the models, and the remaining 15 animal models in VR with the possibility to manipulate them. Each model was presented individually for 5 s before it disappeared (in the *VR* and *Monitor* modality) or was taken back (in the *real* condition), and the next model was presented.

Object manipulation in real-life meant that participants were allowed to grasp, hold and rotate models with their hands. In VR, object manipulation was realized by holding a VR controller close to the computerized animal model and pulling the controller's index finger trigger. The model then followed the controller's movement, allowing the participant to turn and move it in a similar manner as in real-life, but with no tactile input from the model itself. In the computer monitor modality, models could be rotated using the arrow buttons on a keyboard. Here, while the models' rotation in space could be altered, they were not moved in a naturalistic manner using one's hand, and again did not provide specific tactile input.

After each block, participants again saw 2D images of all animal models in a randomized order and were asked to state in which of the last block's two modalities they had seen each animal model. Participants were furthermore asked to rate how confident they were in their attribution on a visual analogue scale ranging from “Not sure at all” to “Very sure”.

After the last block, participants were given two questionnaires about their experience specifically during the VR phases in the experiment. Presence, the sense of “being there” in the virtual environment (Skarbez et al., 2017), was inquired using the German version of the *Igroup Presence Questionnaire* (IPQ; Schubert, Friedmann, and Regenbrecht 2001).

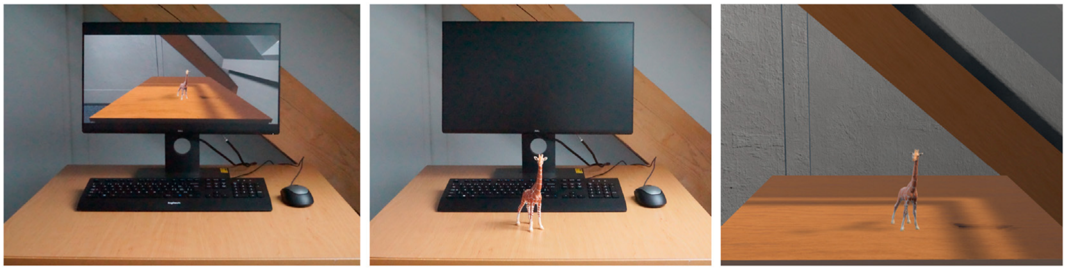

Fig. 1. Stimuli presentation on the computer monitor (left), in reality (middle) and in VR (right). If the virtual stimuli were presented in VR, participants furthermore saw a virtual representation of the controller they were holding in their hand. If the virtual stimuli were presented on a computer monitor, no controller was held or visible in the scene.

Simulator Sickness, a possible negative side-effect when being involved in VR scenarios, was tested using the *Simulator Sickness Questionnaire* (SSQ, Kennedy et al., 1993). Participants then filled out a sociodemographic questionnaire. Participants gave moderate ratings on presence ($M = 50.00$, $SD = 10.79$, on a scale from 14 to 98) and low ratings on simulator sickness ($M = 5.53$, $SD = 3.23$, on a scale from 0 to 48).

2.4. Data processing

Data were analyzed using R for statistical computing (version 3.2, R Development Core Team, 2015). In all analyses, *error rates* refer to the number of attributions of models to a false source modality relative to the total number of models within the relevant subgroup of models. If not stated otherwise, error rates were compared by means of linear mixed models where participant ID was inserted as a random effect and factors of interest were inserted as fixed effects. All parameters were tested for significance using an *F*-test with α set to 0.05. Significant effects in factors with more than two levels were followed up using Tukey's HSD (Honestly Significant Difference). Normality assumption was tested using a Shapiro-Wilk test. Reported correlations are Neyman-Pearson correlations. When model slopes for fixed effects were compared following significant interaction effects, statistical significance of differences was assessed by evaluating if 95% confidence intervals (CI) overlapped.

3. Results

3.1. Source confusion between modalities

In a first analysis, we compared error rates in the three combinations of modalities (Real, VR and Monitor), regardless of the direction of the error and possibilities for object manipulation (see Fig. 2a). For this analysis, models attributed to the VR condition which were actually seen

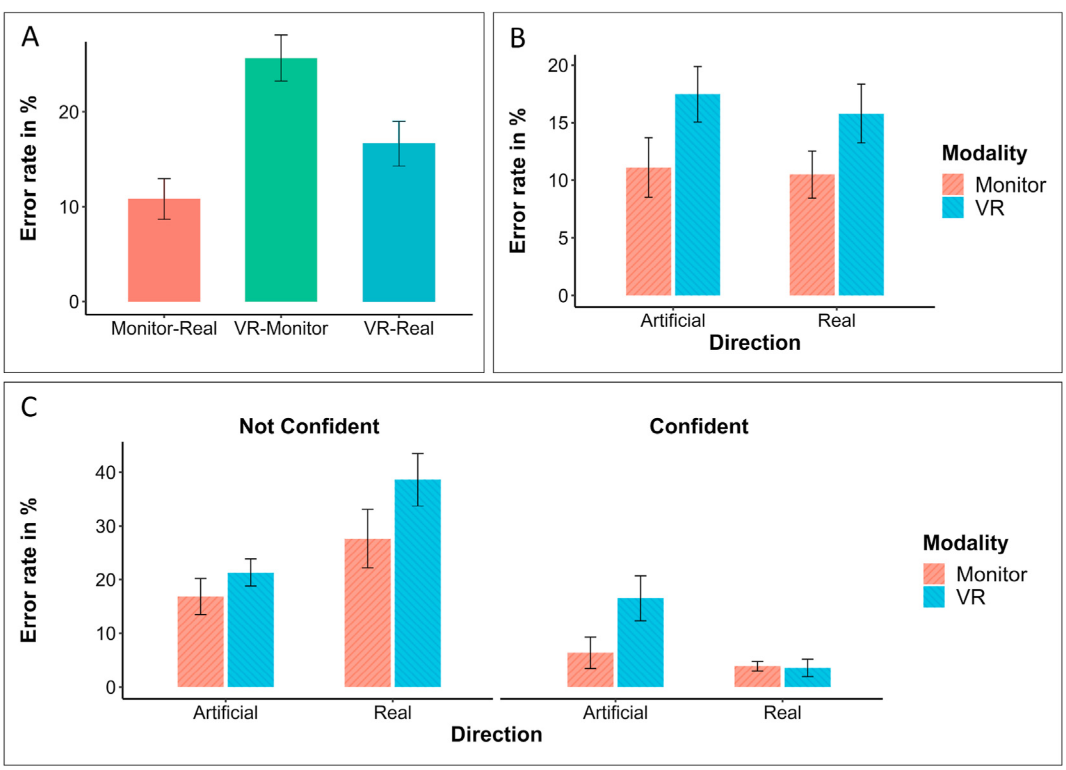

Fig. 2. Error rates in source attribution. (A) The modalities *VR* and *Monitor* were the most frequently confused with one another in source memory, but *VR* and *Real* where also confused more frequently than *Monitor* and *Real*. In this analysis, the direction of the error (if e.g. a model seen in VR is attributed to reality or vice versa) is not regarded. (B) When one of the artificial modalities (*VR* and *Monitor*) and reality were involved in a source attribution task, errors rates were higher when *VR* compared to when *Monitor* was posed against reality — regardless of the direction of the error. (C) Separates data from (B) between source attributions for which participants did vs. did not express high confidence. When participants expressed high confidence, error rates were indeed lower. Most notably, however, error rates here were still comparatively high for models seen in *VR* compared to each of the three other error categories. Error bars represent SEM.

on a monitor and models attributed to the monitor condition which were actually seen in VR were both counted to the error type *VR-Monitor*, and were contrasted against errors in the corresponding error types *VR-Real* and *Monitor-Real*. Across all conditions, 18.03% ($SD = 8.83\%$) of participants' source attributions were incorrect, indicating that the task was relatively easy compared to several *who-said-what* experiments where error rates were around 50% and above (e.g. Pietraszewski & Schwartz, 2014). We found a significant effect of the error type ($F(2,35) = 25.38$, $p < .001$). Models presented in blocks in which participants were confronted with a VR and a monitor modality (*VR-Monitor*) were the most likely to be misattributed with an average error rate of $M = 25.64\%$ ($SD = 10.54\%$), while error rates in *VR-Real*-blocks ($M = 16.64\%$, $SD = 10.27\%$) and *Monitor-Real*-blocks ($M = 10.80\%$, $SD = 8.99\%$) were lower. Post-Hoc analyses revealed that differences in error rates were significant between *VR-Monitor* and *Monitor-Real* ($p < .001$), *VR-Monitor* and *VR-Real* ($p < .001$) as well as *Monitor-Real* and *VR-Real* error types ($p = .03$).

3.2. Mistaking VR and monitor for reality, and vice versa

The previous analyses revealed that errors in source monitoring were most frequent between the *VR* and the *Monitor* modality, but *VR* and *Real* were also more likely to be confused with each other than *Monitor* and *Real*. Focusing on the source memory's performance with regards to the "traditional" monitor modality compared to the more "novel" VR modality, we followed up on this result by more closely investigating the *VR-Real* and *Monitor-Real* error types (Fig. 2b). We represented data from these blocks along the factors *modality* (*VR* or *Monitor*) and *direction* (*artificial*: models were originally seen either in *VR* or on a *monitor*; *real*: models were originally seen in *Real*). For instance, error rates in the *VR/artificial* subgroup of trials refer to the percentage of the models seen in VR which were mistakenly attributed to be real.

We found a significant effect of the modality ($F(1,52) = 15.77$, $p < .001$), but no effect of the direction ($F(1,52) = 0.72$, $p = .40$) and no modality × direction interaction ($F(1,52) = 0.15$, $p = .70$). When models were originally seen in reality, error rates were $M = 10.49\%$ ($SD = 8.68\%$) in blocks where the alternative modality was a monitor and $M = 15.79\%$ ($SD = 11.11\%$) in blocks where the alternative modality was VR. When models were originally seen in one of the two artificial modalities and the alternative modality was reality, error rates were $M = 11.11\%$ ($SD = 10.95\%$) if the artificial modality was a monitor and $M = 17.49\%$ ($SD = 10.51\%$) if it was VR. This analysis again showed that the modalities *Real* and *VR* were more frequently mistaken for one another in participants' source memory compared to the modalities *Real* and *Monitor*, and added that this effect did not depend on the direction of the source monitoring error.

3.3. The role of confidence in source monitoring errors

Next, we analyzed the role of participants' own confidence judgement on their error rates (Fig. 2c). Confidence ratings were not normally distributed across the experiment ($W = 0.79$, $p < .001$). Specifically, participants gave the highest possible confidence rating in 43.98% of their decisions. The median confidence rating was 0.91 on a scale from 0 (not confident at all) to 1 (very confident). Participants' average confidence ratings, by contrast, did not deviate from a normal distribution assumption ($W = 0.96$, $p = .59$). A significant negative correlation between participants' average confidence ratings and their average error rates along the whole experiment ($r = -0.58$, 95%-CI = [-0.82, −0.17], $p < .01$) revealed that participants' rating bias in their confidence were not merely idiosyncratic but corresponded well to their actual memory performance. In order to investigate the correlation between confidence judgements and error rates within different error types, we classified confidence ratings as *confident* when confidence was above the median of 0.91 and as *not confident* otherwise.

Due to partial redundancy with analyses above, comparisons of source attribution errors in consideration of expressed confidence are described in full detail in Supplementary Results. In brief, we found a positive confidence-accuracy-relationship ($p < .001$) which was strongest for the *VR-Monitor* error type. The confidence-accuracy relation was stronger for models which were seen in the real environment compared to models which were seen in an artificial environment ($p < .001$). Among the non-confident decisions, error rates here were higher for models seen in reality compared to models seen in an artificial modality ($p < .04$). Among the confident decisions, we found highest error rates for models seen in VR ($p < .05$). In other words, participants were most overconfident about the accuracy of their source identifications of memories from VR.

3.4. The role of model manipulation in source monitoring errors

We then analyzed whether the possibility to interact with a model facilitated a correct source attribution, and whether such a facilitation effect was strongest for real models and weakest for models seen on a monitor. When including a modality (real, VR or monitor — regardless of the alternative's modality in each block), interactivity and a modality × interactivity as fixed effects, we again found an effect of the modality ($F(2,83) = 4.24$, $p = .02$), but no effect of the interactivity ($F(1,83) = 0.45$, $p = .51$) and no modality × interactivity interaction ($F(2,83) = 1.08$, $p = .35$). Across the whole experiment, there was no evidence that interacting with models increased or decreased source memory performance for any of the three modalities.

4. Discussion

We investigated systematic errors in memory source attributions for models which were seen either in reality, in VR or on a computer monitor by using a modification of the *who-said-what* paradigm and virtual reality monitoring paradigms (Hoffman et al., 2001). Confusions between VR and the computer monitor modality were the most frequent, but confusions between VR and reality were also more frequent compared to confusions between the computer monitor modality and reality, indicating that VR was processed as more real compared to the computer monitor modality in the participants' source memory system. This effect did not differ between the two possible directions of the error (i.e. if a model seen in VR was attributed to reality or vice versa).

Confidence ratings were indicative of source attributions' accuracy. The confidence-accuracy relation was stronger when the VR and the computer monitor modality were pitted against each other compared to the other two combinations of modalities. This means that contrary to our prediction, the most frequent error type (indicating the most difficult task) was associated with the strongest confidence-accuracy relation. When incorporating the direction of memory confusions between the real modality and both artificial modalities, we found a stronger confidence-accuracy relation for models seen in reality. Interestingly, this effect was partly driven by a relatively high error rate among high-confident attributions for models seen in VR. In other words, when participants saw a model in VR, they were comparatively likely to attribute it to reality and express high confidence for their wrong attribution. The possibility to interact with the models, which differed in terms of perceptual detail between the three modalities, was not found to influence error rates.

The finding that the source memory system is more prone to confusing VR and reality compared to a monitor-based presentation and reality provides further evidence for the idea that stimuli presented in VR are processed in a more naturalistic manner — thus providing higher ecological validity — compared to stimuli presented in a computer monitor. More specifically, this finding is in line with previous observations that VR (Aronov & Tank, 2014; Harvey et al., 2009) but not scenes viewed on a computer screen (Li, Arleo, and Sheynikhovich 2020) can activate place cells similarly to real-world experiences. Such neurons were found to not only encode a person's current location, but also the location of where a specific object was previously encountered (Qasim et al., 2019), thus providing a neural mechanisms to give memories an episodic character (Ekstrom & Ranganath, 2017; Mitchell & Johnson, 2009) and to ultimately help form autobiographical memories (Boccia et al., 2019). Since autobiographical stimuli are inherently embedded in representations of places (Lengen et al., 2019; Riva et al., 2021), experiences in VR may thus more strongly involve our sense of self and unique personal identity compared to the viewing of scenes on a computer monitor.

At the same time, the present study did not resolve specifically which of the various ways in which VR resembles reality are relevant to produce this difference in memory performance. One candidate variable — the differing forms of object interaction as they are typical for each modality — was not found to influence source memory performance. At the same time, a variety of other factors which may possibly be relevant for the source memory system were not individually controlled. For instance, VR but not a computer monitor allows to inspect objects using binocular vision and by moving one's head. Furthermore, objects in VR are perceived to be located in the same space in which one feels present oneself, but are bound to a 2-dimensional frame when viewed on a monitor. By contrast, with the VR system used here, objects were presented in a more pixelated manner compared to standard computer monitors, and unlike viewing an object in reality or on a monitor, VR equipment is positioned on a viewer's head, creating additional tactile input. Moreover, participants in the present experiment could not see their own body (or even a virtual representation of it) while viewing objects in VR. Interestingly, Bréchet et al. (2019) found that taking ownership over a virtual body in VR can generally improve memory performance for objects seen in the virtual scenario, but might further impede its differentiation from real experiences in the source memory system. In sum, while the present study demonstrates that the source memory system is more prone to confusing reality and VR as it is typically used compared to reality and computer monitors, additional research is needed to more closely describe the processes which contribute to this effect.

The finding that the source memory system is relatively prone to confusing VR and reality may point to both benefits and possible dangers of using VR technology. On the one hand, source memory confusions may partly explain why positive treatment effects obtained in VR programs often generalize well to real life (Freeman et al., 2017; Morina et al., 2015). For instance, patients suffering from height phobia may habituate to standing on a virtual tower in VR and later experience decreased fear responses in real height situations. Similarly, compared to VR therapy with no tactile feedback, a group of spider phobics who physically touched a hairy virtual spider in virtual reality during exposure therapy (using tactile augmentation) were able to approach significantly closer to a live tarantula post-treatment, during a behavioral avoidance test (Hoffman et al., 2003). The present study suggests that corrective experiences in VR may partly be processed as real experiences due to a blur between these two modalities in the source memory system. Following this idea, future research may investigate if inter-individual differences in VR-related source memory performance are predictive of treatment generalization following VR-based therapies, thus helping to better match individual patients to specific treatments according to their needs (Norr et al., 2018). However, it must be noted that while generalization effects for psychotherapeutic interventions are typically assessed weeks or months after the treatment, source memory performance in the present study was assessed immediately after each experimental block. Future research may additionally assess source memory performance over an extended period of time in order to better understand the temporal trajectory of source tag confusions between VR and reality relative to other types of source tag confusions.

On the other hand, as VR is more and more commonly employed in professional contexts (Berg & Vance, 2016), difficulties to distinguish real from virtual experiences may arise as an unwanted side-effect. Here, one may consider an architect who spends an increasing amount of time working within virtual representations of construction sites and who may loose track of the places he or she has physically visited. The problem may be enhanced with increasing age, when source memory performance is known to decrease even stronger than item memory performance (Glisky et al., 2001).

Summing up, the present study demonstrates that differentiating VR from reality provides a greater challenge to the source memory system compared to differentiating monitor-based presentations from reality. While this finding highlights the more naturalistic processing of stimuli in VR compared to traditional monitor-based setups and the utility of using VR to increase ecological validity, future research is required to identify the precise mechanisms underlying this effect and to deepen our understanding of possible benefits as well as dangers of using VR technology.

Data availability

The data that support the findings of this study are available at Anonymous.

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.

Acknowledgements

This work was supported by SNF 100001C_185387 and SNF PP00P1_170503. The authors thank Leoni Raab for her help in stimulus generation and Suzana Komericki and Janosch Lieb for their help in data collection.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.chbr.2021.100111.

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