Using Visual Cues to Prevent Memory Confusion Between the Virtual and the Real in Augmented Reality

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Abstract

As augmented reality technologies advance, the potential for creating hyper-realistic experiences grows, raising concerns about users confusing virtual content with reality. This paper explores ways to mitigate source confusion, a form of false memory where virtual content is misremembered as real and vice-versa. Building on previous studies on source confusion, it proposes a methodological framework for evaluating the capacity of visual cues to reduce source confusion in augmented reality.

CCS Concepts

• **Human-centered computing → Empirical studies in HCI**.

Keywords

False Memory, Source Confusion, Augmented Reality

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1 Introduction

With the current trend to make virtual imagery increasingly realistic [15, 17, 23, 31], researchers have identified risks posed by blurring the line between virtual and real content, and the need for design guidelines to help users distinguish between the two [4, 19, 33]. Such guidelines are especially crucial for AR because, unlike virtual reality (VR), AR integrates virtual elements directly into the real world, making the line more fuzzy and the distinction more challenging. Mitigating source confusion in AR has significant real-world implications for misinformation, decision-making, and user trust.

Even when users can tell real and virtual elements apart, they might later recall real elements as virtual or vice versa, a type of false memory psychologists call *source confusion* [16, 32]. For example, imagine Max walks in a city with a wearable AR display, and sees an ad for a future coffee shop in the form of a virtual coffee shop with virtual customers. He knows it is not real, but later he misremembers it as real and mentions it to his friend. Some studies have already demonstrated source confusion in VR [3, 12, 30] and AR [8]. The more similar two sources are, the more likely they are to be confused [16], so source confusion may become increasingly common as virtual elements become more realistic.

Building on prior work on the ethics of AR and on memory, we present an ongoing work that examines ways in which source confusion in AR can be mitigated with *visual cues*. By visual cue we mean a visual effect that makes a virtual object visually distinct from its physical environment and highlights its virtual nature. Figure 1 illustrates possible visual effects, inspired by visual codes used in works of fiction. Our working hypothesis is that the choice of visual cue has an effect on how likely people will be to confuse virtual and real in their memories. For example, had the virtual coffee shop and customers in our example used obvious visual cues (e.g., monochromatic tones, glow and translucency), Max might have correctly remembered the coffee shop as virtual.

We start by providing an overview of the related work, including a survey of studies investigating source confusion in VR and AR. We then propose a study protocol for measuring the capacity of visual cues to prevent source confusion.

2 Related work

We summarize what we know about false memories from a cognitive psychology perspective. Then we provide an overview of studies of false memories in XR (i.e, VR and AR [28]), and research on the perception of virtual content.

2.1 Source Confusion

Memory is widely recognized as fallible. Schacter [32] defines three categories of memory flaws: forgetting, persistence, and memory distortion. Among memory distortion flaws is misattribution, also referred to as source confusion [16], where people attribute the wrong source to a memory [32]. The concept of source is broad and multidimensional [27]; For example, suppose Paul and Max had a chat at work, and Paul told Max that a tornado recently hit the US. The source can be defined by where and when Paul learned the information (at work), the medium through which it was delivered (in a discussion), or the person who shared it (Paul). According to the source memory framework [16], sources can be external (e.g., TV, a journal) or internal (content from our own memories), and they are reconstructed. That is, they are inferred from the memory's content and prior knowledge through an unconscious and rapid cognitive process. Two sources sharing overlapping perceptual and semantic characteristics can lead to source confusion [20]. For example, a study found that people are more likely to experience source confusion when watching a TV program that blends news and fiction with similar visual content, compared to when the content is visually distinct [22].

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Figure 1: Examples of elementary visual effects used to depict virtual objects in popular culture.

2.2 Source Confusion in XR

We know of five studies looking at whether people misremember virtual content as real or vice-versa [3, 8, 10, 12, 30]. All five studies followed a two-step process: first, people perform what we call an *observation task*, where they observe a set of virtual and real objects. Then, after a time period that varies across studies (from immediately after to two weeks later), participants perform an *identification task* during which they complete a source confusion test. During this test, they are shown objects they saw before as well as new objects, and are asked to recognize the objects they saw. For those, they are further asked to indicate if they were virtual or real.

Four of the five studies measured source confusion between 3D objects shown in VR and real objects, including two pioneering studies conducted 25–30 years ago [10, 12] and two studies conducted more recently [3, 30]. They found a rate of source confusion ranging from 17% to 27%. One of the studies [30] tested if interacting with the objects reduces source confusion, with inconclusive results. The fifth study [8] measured source confusion between 3D geometrical shapes shown in webcam-see-through AR, and 3D-printed shapes shown through the same webcam. Source confusion occurred more than 40% of the time (i.e., close to random guessing), but went down to 27% when participants could manipulate the objects.

Of the five studies we reviewed, three [3, 8, 12] found that participants were more likely to classify real objects as virtual than the other way around, a phenomenon called the "it-had-to-be-virtual effect" [12]. A postulated mechanism is that memories of virtual objects are believed to be inherently weaker than those of real objects, so when a person has a weak or degraded memory of an object, they tend to assume it was virtual [11, 12]. This aligns with the idea that source identification involves comparisons with prior knowledge and assumptions about XR environments [3, 12].

On the other hand, indirect evidence suggests that people may use visual cues for source identification, such as visual imperfections in the texture, level of detail, shape, size, colors, and dynamic behavior of virtual objects, arising from limitations of 3D models and XR displays [3, 12]. However, no study we know of has directly tested the effect of such imperfections on source confusion. More generally, we do not know of any source confusion study that explicitly manipulates the ways in which real and virtual objects visually differ. Although those differences can be accidental (e.g., display imperfections), they can also be intentional. Here we are interested in studying intentional visual cues, in the anticipation that accidental visual cues will progressively lose importance with improving technology.

2.3 Reasons For & Against Hyper-Realistic AR

Realism in AR is sometimes desirable, and end users may want realism for various reasons, including for aesthetic purposes. For example, a person may want to use AR to display a beautiful landscape outside their window—and such applications already exist [26]. If the landscape looks obviously computer-generated, it could lose all its appeal. Realism has also been proposed as an alternative aesthetic for AR that moves away from overpowering and distracting visuals, instead promoting a calmer, more contemplative experience [1]. End users may also desire realism to feel more immersed while engaging with AR games, movies, and documentaries. Meanwhile, educators and communicators may want to leverage realistic virtual content to promote information retention [13, 21].

Of course, realistic AR also comes with dangers. Researchers have already discussed potential ethical implications of hyper-realistic AR, including its possible effects on cognition and perception [33]. For example, offering persuasive virtual content that seems real can change people's perception of the real world [33]. Because of these risks, Li and colleagues [19] argue that XR designers need to develop a visual language to help users distinguish between virtual and real content, and give them control over how virtual content is displayed. Similarly, researchers have discussed the concept of "de-augmenting" AR, i.e., giving end users full control over the amount of virtual content displayed in their physical environment [5]. Our work finds its motivation in this line of research—our vision is that, once we understand the visual cues that effectively prevent confusion and misremembering, AR hardware and content providers will be encouraged or incentivized to support them, and end users will have the freedom to toggle them on and off.

2.4 Research Towards More or Less Realism

Desirable or not, hyper-realistic AR is still technically out of reach, the biggest challenge lying in achieving visually coherent representations that seamlessly integrate virtual and real content [7]. Virtual objects in AR generally suffer from a range of visual imperfections, such as inconsistent lighting and inadequate occlusion [18, 24, 36], as well as behaviors that violate laws of physics [24]. However, a

line of research focuses on making AR technology more realistic [15, 17, 23], so this problem may eventually be solved.

Although maximum visual realism is generally the goal of computer graphics research, a stream of research called non-photorealistic rendering (NPR) has the goal of producing images that do not look real [34]. However, the purpose of NPR is generally not to help people distinguish virtual from real content ; rather, NPR is generally used for aesthetic purposes, often through the imitation of hand drawing and painting techniques [34]. NPR studies look at how such images are perceived, the degree to which they are able to imitate artistic techniques, and their emotional impact [2, 14].

3 Proposal for a Study Protocol

We are planning to run a study to test the capacity of different visual cues to reduce source confusion in AR. We describe our study protocol here, as well as possible variations, in case other researchers wish to conduct a similar study. Our study will consist of two parts: a pre-test and a source confusion experiment.

The purpose of the pre-test will be to calibrate the intensity of the visual effects. It will consist of a series of visual search tasks, where participants must find a target stimulus (an object with a visual effect applied) among distractors (objects without effects) as quickly as possible. This test will give us a measure of the perceived intensity of different visual effects with different settings, allowing us to calibrate the effects to have the same perceived intensity in the source confusion experiment. We will target two intensity levels (subtle and obvious).

The source confusion experiment will be divided into two parts. During the observation task, participants will examine real and virtual objects. At this stage, they will remain unaware of the experiment's true purpose, so they do not try to voluntarily memorize the objects or the sources, but instead experience them as they would in a typical daily-life scenario. Ten days later, participants will be asked to complete a source confusion questionnaire, which will assess their ability to correctly recall the source (virtual vs. real) of the objects they saw.

3.1 Experiment Design Rationale

As mentioned in the introduction, our focus is not on studying current XR technology, but rather on posing questions that anticipate future advancements. We anticipate a future where virtual content can be made visually indistinguishable from real content, potentially necessitating visual codes to help users tell them apart. Thus, our study differs from previous similar studies on source confusion [3, 8, 12, 30] in that it needs to carefully control the ways in which virtual objects visually differ from real objects. This implies major methodological differences that we explain and justify here.

3.1.1 *Video Format.*

We will use videos depicting real and virtual objects instead of presenting real and virtual objects to participants using, e.g., head-mounted AR displays or mobile AR. The reason is that it is challenging to finely control for visual cues using current AR systems, as virtual objects in such systems already visually differ from real objects in multiple uncontrollable ways. In contrast, there exist a range of tools for producing videos with special effects with a high degree of control. We chose to use videos instead of still images for two reasons: first, we want to be able to test dynamic visual cues, such as flicker, glitch, or appearance. Second, the videos will involve slow camera motions, in order to mimic real AR situations where the user is allowed to inspect real and virtual objects from different angles.

3.1.2 *Online Study.*

Because both the source confusion experiment and the pre-test for calibrating the visual effects require numerous participants to ensure robust and reliable results, both studies will be conducted online. We will use a crowdsourcing platform for academic research (Prolific), which will give us access to a large and diverse pool of participants. Because our experiment uses videos as stimuli and requires no special display hardware, running the full study online will be straightforward.

3.2 Material

We explain here how we will select objects and visual cues, and how we will generate the video stimuli.

3.2.1 *Object Selection.*

Following previous studies [3, 12, 30], we will use a set of 30 common objects for the experiment. We are planning to select objects using the Object Memorability Image Normed Database Software (O-MINDS) [9]. This software allows to automatically choose items from a bank of 1,748 normed images based on their memorability, nameability, and emotionality, as well as responses to questions such as "Is it larger or smaller than a shoebox?", "Is it human made or natural?", "Is it used indoors or outdoors?".

3.2.2 *Cue Selection.*

Many possible visual cues can be tested. We must first identify reasonable candidates, i.e., cues we have reasons to think will allow people to easily distinguish virtual from real content. One possible source of inspiration originates from the visual conventions used to depict virtual objects in popular culture, e.g., science-fiction movies, concept videos, mangas, and video games. In order to better understand those conventions, we are currently collecting examples of virtual objects or virtual people featured in works of fiction. We have surveyed 151 works of fiction so far, and will soon move to a qualitative coding phase. Figure 1 illustrates some of the visual effects we have encountered. These are elementary effects, which can be (and often are) combined. We also identified dynamic effects such as impermanence (i.e., appearance and disappearance), flickering, glitches, and spontaneous deformations. A second way to collect candidate visual cues is by referring to literature on perception of virtual and real objects and on common imperfections of virtual objects (see subsection 2.4). We have not pre-selected any visual effect at this stage. We will do so using multiple criteria such as feasibility, legibility, and compatibility with accessibility norms.

3.2.3 *Stimuli Generation.*

Having identified objects and visual cues, a major methodological issue will be how to create the video stimuli for the real and virtual conditions. Ideally, we would like to shoot videos of real objects, and have ultra-realistic 3D models of the same objects to which we apply our visual effects. However, even in carefully-crafted videos, computer-generated objects may differ from real objects in uncontrolled ways, introducing confounds that can invalidate our findings. Such confounds can be eliminated if both experimental conditions use the same real objects, or the same

Method	Environment	Real object	Virtual object	Tools required	Full effect control?	Can do any effect?	Real object is real?	Virtual object is virtual?
1 – Full 2D	Video-recorded	Video-recorded	Video-recorded with 2D effects	Video VFX tool (e.g., After Effects)	Yes	× No	Yes	× No
2 – Full 3D	3D-rendered	3D-rendered	3D-rendered	3D modeling tool (e.g., Blender)	Yes	Yes	× No	Almost
3 – Hybrid	Video-recorded	Video-recorded	3D-rendered	3D modeling tool, image-based lighting, 3D scanner	× No	Yes	Yes	Almost
4 – Hybrid	Video-recorded	3D-rendered	3D-rendered	3D modeling tool, image-based lighting	Yes	Yes	× No	Almost
5 – Hybrid	Video-recorded	Video-recorded	Video-recorded with 3D effects	3D modeling tool, 3D scanner	Yes	× No	Yes	× No

Table 1: Possible methods for generating stimuli for our study.

computer-generated objects. Table 1 summarizes the trade-offs of different stimulus generation methods.

Suppose we need a video of a teapot placed on a table, with and without a glowing effect (see Figure 1-e). Method #1 (Full 2D) involves taking a video of a real teapot placed on a real table, and using a VFX tool to generate an alternative version in which the teapot glows. We then use the original video for the real condition, and the retouched video for the virtual condition. This approach has the advantage of ensuring no uncontrolled discrepancy between the real and the virtual object—we have full control over the visual effect. However, some effects such as the wireframe effect (Figure 1-i) may be difficult to achieve in 2D. Another issue is that while the real condition does show a real object, the virtual condition actually only shows a real object to which a visual effect has been applied. This mismatch requires either asking participants to ignore the true nature of the stimulus and imagine a hypothetical situation where it is a virtual object, or hiding the true nature of the stimulus, with the risk that participants detect the deception.

Method #2 (Full 3D) involves using 3D modeling to create everything from scratch: the table, the normal teapot, and the glowing teapot. This approach gives again full control over the visual effect, without unwanted discrepancies between virtual and real objects, but it supports a wider range of effects (e.g., the wireframe effect becomes feasible). Also, this time, the virtual condition shows an object that is approximately virtual—i.e., its image is computer-generated, although not interactively or in real-time, which is generally implied by the word "virtual" [6, 25]. However, a major drawback of this method is that the real condition does not actually show a real object; If deception is used, the risk of detection is high, unless considerable efforts are spent at producing ultra-realistic videos and pre-testing them.

Finally, several hybrid methods are possible. Method #3 is similar to Full 2D except the virtual condition is obtained by compositing a 3D-generated teapot into a video of an empty table. This method combines some of the advantages of Full 2D and Full 3D, but does not eliminate the possibility of confounds arising from visual discrepancies between real and 3D objects. Even with considerable efforts spent at obtaining 3D models that closely resemble the real objects (using, e.g., 3D scanning), such confounds cannot be eliminated with certainty. Method #4 is similar except the real object is also 3D-rendered. This method has similar trade-offs as Full 3D, but may make it easier to achieve high realism, especially of camera movements. Finally, Method #5 is similar to Full 2D except the virtual condition is obtained by applying a 3D effect to the real teapot. With this method, one can easily add overlays to create advanced 3D effects (e.g., a wireframe), but effects requiring the object itself to be modified (e.g., translucency) might be difficult to achieve.

For our study, we started by testing method #4 but then excluded it, as we are not confident that we can produce sufficiently realistic videos. We carried out successful tests of method #1 and are considering using it, but we have not entirely excluded method #2 and are currently evaluating its feasibility.

3.2.4 Pre-test for Calibrating Visual Effect Intensities. Most of our candidate visual effects (see Figure 1) can be applied with settings of different strengths—e.g., an object can be made more or less translucent, or more or less luminous. The stronger a visual effect, the more distinct the object becomes from a real object. Since two sources sharing similar characteristics are more likely to be confused [20], it is likely that the intensity with which a visual effect is applied affects source confusion. Since our main goal is to compare different types of visual cues, using effects with arbitrary settings can introduce major confounds. For this reason, we will run a pre-test to calibrate effect intensities.

Calibrating the intensity of different visual effects requires measuring their subjective (perceived) intensity, which can be done in many ways. One way is to apply the visual effect to various objects and measure how much they stand out next to regular objects, i.e., their visual saliency. Studies suggest that the more salient a visual object is, the shorter the time required to find it [35]. Therefore,

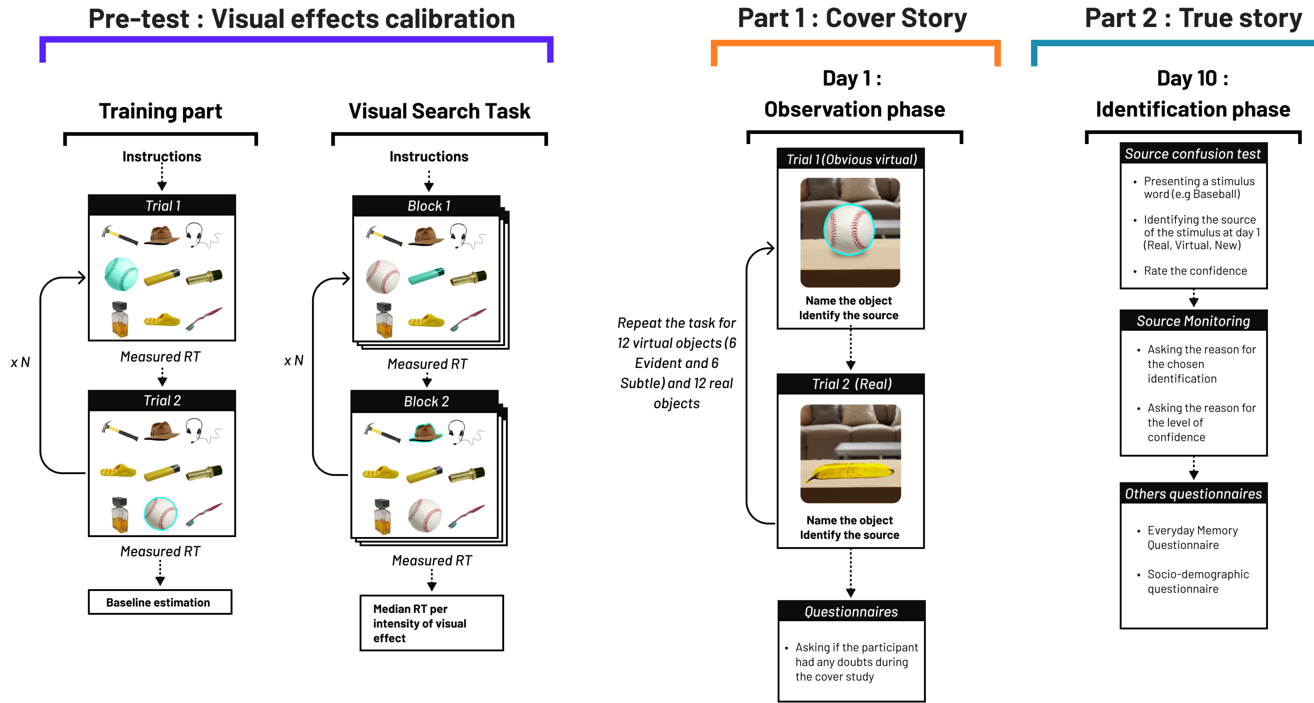

Figure 2: Procedure for the pre-test (left) and for the source confusion experiment (right).

the pre-test will employ a visual search task to assess the perceived intensity of different visual effects with different settings strengths. During each trial, participants will see a 3×3 grid containing an object with a visual effect applied (the target) and eight other objects without any effect (the distractors). Participants will be asked to identify the target as quickly as possible, while prioritizing accuracy over speed. We will then compute the average search time for each (effect type $\times$ settings strength) combination, and will choose settings that yield comparable search times across effect types. For example, if a 10% transparency and a two-pixel yellow outline lead to similar search times, the two visual effects will be considered calibrated.

We will calibrate the effects for two global intensity levels: a subtle one and an obvious one. This will allow us to include intensity as a secondary independent variable in our main experiment. Our expectation is that subtle effects will lead to more source confusion than obvious effects, for the reasons mentioned before.

We plan to recruit between 20 and 40 participants for this pre-test. Figure 2-left presents an overview of the procedure. Participants will first undergo a training session with practice trials. They will then take a break and proceed to the main phase, divided in several blocks. Each block will focus on a specific type of visual effect presented with various strengths. The order of blocks and of trials within blocks will be fully randomized.

3.3 Source Confusion Experiment

The experiment's method is largely inspired by previous studies of source confusion in XR (see subsection 2.2). As in previous studies, it consists of an observation task (part 1) followed by an identification task (part 2)—see Figure 2-right.

3.3.1 Experiment Design. The experiment has two independent variables: one is *display type*, with three conditions: *real* (video of an unaltered object), *subtle virtual* (object with a subtle visual cue), and *obvious virtual* (object with a prominent visual cue). This variable is within-subject, meaning each participant will see all three display types. The second independent variable is *cue type*, i.e., the type of visual cue used in the virtual conditions, with 4 to 8 conditions yet to be decided (see subsubsection 3.2.2). This variable is between-subject, meaning each participant will only see one type of visual cue to prevent contimation between the cues. Each participant will be exposed to only one type of visual cue to prevent contamination between cues, ensuring that the effects remain isolated and uncontaminated by other experimental materials.

The main dependent variable is the percentage of source confusions measured in part 2.

3.3.2 Observation Task Procedure (Part 1). This task will be administered online, on the Prolific platform. Participants will be unaware of the study's true purpose, and will be simply told it is about the perception of virtual and real objects. They will be explained that they will see short videos of real objects and virtual objects, and that virtual objects will look different (with an illustration of the visual effect assigned to the participant). They will then see a series of videos of familiar objects lasting about 10 seconds, shown in different display conditions ($^1/_2$ of the videos will be assigned to *real*, $^1/_4$ to *subtle-virtual*, and $^1/_4$ to *obvious-virtual*). For each video, they will be asked to name the object and indicate whether it is real or virtual. We plan on using 24 trials, but this number may change depending on the number of visual cues we will test. Finally, participants will answer a cover study question, asking if they had any

doubt about the true purpose of the study. Data from participants who had doubts will be excluded from the main analyses.

3.3.3 Identification Task Procedure (Part 2). This task will be administered about 10 days after the observation task, also on Prolific. Participants from Part 1 will be notified that they can complete a follow-up study. Those who agree will pass a source confusion test adapted from previous studies [3, 12]. Participants will see a series of words, some referring to an object they saw in Part 1, and some referring to objects they did not see. They will be asked to state if they saw the object as a real object, as a virtual object, or if the object is new. They will also be asked to rate their confidence in their answer. Then, a source monitoring questionnaire [3] will be used to gather qualitative feedback, and help us identify the cues used by participants to perform source attribution. Finally, participants will fill an everyday memory questionnaire [29] and a short demographic questionnaire, that will help us characterize our sample and determine possible interactions or moderating effects between personal characteristics and source confusion.

3.3.4 Participants. We plan to recruit 100 to 200 participants for this experiment (to be determined by a power analysis).

4 Conclusion

As XR technology matures, there is a growing need to develop guidelines to prevent confusion between virtual and real elements, especially in AR systems where both are intertwined and may be experienced for extended periods of time. Researchers have demonstrated that current XR systems are capable of generating source confusion, and have warned that source confusion may get worse with better XR systems. However, to our knowledge, no study has looked at how a visual language can mitigate source confusion. We fill this gap by reviewing relevant work and presenting a methodological framework for selecting, calibrating, and evaluating visual cues in order to reduce source confusion in AR. As our next step, we will preregister and run a study based on this framework.

We anticipate that our results will offer the HCI community insights on whether visual cues can effectively reduce confusion between virtual and real elements, whether some cues are more effective than others, and how strong the cues need to be. If visual cues prove effective, our findings will provide preliminary guidance for designers and developers on creating AR experiences that are ethical and respect people's autonomy, while also helping policymakers prevent nefarious uses of such technologies. Additionally, we hope that our findings will contribute to cognitive sciences by shedding light on the mechanisms through which people encode and reconstruct memories of virtual content.

Our study protocol is not without limitations, and studies using different methodologies will need to be conducted. Specifically, while a video-based online experiment is useful for controlled testing, it does not fully capture the immersive and interactive aspects of AR experiences. Future studies involving actual AR systems will be needed to validate and generalize our findings across a broader range of real-world AR use cases and more diverse user groups. However, this approach presents important challenges, as current AR technology limits fine control over visual cues, and recruiting large participant samples for in-lab studies is difficult.

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