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The Impacts of Visual Effects on User Perception With a Virtual Human in Augmented Reality Conflict Situations

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ABSTRACT Virtual humans (VHs) in augmented reality (AR) can provide users an illusory sense of being together in the real space. However, such an illusion can easily break when the augmented VH conflicts (or is overlaid) with the real objects. Recent spatial understanding technology is starting to make physically plausible VHs in response to collisions, but there are still limitations (e.g., resolution, accuracy) and inevitable conflict situations (e.g., unexpected passer-by), especially in daily life. Moreover, depending on the situation, VH's plausible behavior to avoid collision may rather interfere with the original interaction with the users. In this paper, we investigate three such situations: (1) when VH appears in a room through a closed door, (2) when the VH's body overlaps with static real objects, and (3) when a real moving object passes through the VH. While we considered (2) as an avoidable situation where physically plausible behaviors of VHs might be required, (1) and (3) were considered as inevitable situations (e.g., VH appearing out of nowhere, or passer-by cannot be aware of a virtual being), and we may not present VH's plausible behaviors, so alternatives might be required. Thus, for each of these notable situations in AR, we tested different visual effects as presentation methods for physical conflicts between a VH and real objects. Our findings indicate that visual effects improve VH's social/co-presence and physicality depending on the situations and effect types as well as influence users' attention/social behaviors. We discuss the implications of our findings and future research directions.

INDEX TERMS Augmented reality, pervasive AR, virtual human, visual effects, perceptual issue, physicality conflict, social presence, co-presence, inevitable collision, human perception.

I. INTRODUCTION

Virtual humans (VHs) refer to human-like computer graphics manifestations. Due to their human-like appearance, people tend to expect (or interact with) VHs to behave in a similar way to real humans who use various social cues nurtured through ones' past experience and innate by evolution. To explain such interactions with VHs, researchers have adopted the terms social presence and co-presence. In this paper, we use the term ''social presence'' as the sense of being socially connected with a real sentient being, and ''co-presence'' as the sense of being together in a shared space according to the definitions given by Skarbez *et al.* [1]. We also use social/co-presence to refer to both meanings.

A notable change in VH research in the past decade has coincided with the advances in augmented reality (AR) technologies. Thanks to the spatial sensing technologies in AR head-mounted displays (HMDs), VHs now can share the real space with users and interact with the surrounding physical objects [2]. However, VHs overlaid in real space brought challenges in inducing the sense of co-presence. For example, optical-see-through (OST) AR HMDs' small field of view and the semi-transparent images hinder users from feeling co-presence with VHs [3]. The challenge is that, unlike real

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FIGURE 1. In our experiment, the augmented virtual human appears to the user in real space. (a) The virtual human is initially outside the room behind the door. Then he walks through the closed door in three ways: (b) fade-in/out effect, (b) flare-up effect, and (d) mere overlap as-is.

people, parts of the VH's body are invisible or transparent in OST AR, like a ghost. Besides, the dynamical nature of real environments makes it difficult for VHs to respond to real events plausibly while complying with physical rules [4].

Failure to obey physical rules (it called a physicality conflict) can reduce co-presence with VHs [5]. For example, a situation in which VHs overlapped with or passing through the real object (ROs) can remind users of their virtualness and eventually lead to breaks in the illusory sense of being together in the same physical space (i.e., co-presence) [5], [6]. Though the advanced 3D understanding technology may detect and prevent most of such collision situations [7]–[9], some situations still remain and inevitable conflicts with VHs can occur. For example, if a user summons a VH in a closed room, the VH needs to either suddenly appear from thin air or pass through a wall. Moreover, there can be simple passer-by (obviously without any means to view AR images) in the real space, who are not aware of the existence of VHs, will just pass through the AR interaction space occupied by VHs. Although recent VHs may detect the motion of passer-by and avoid collisions with them, such behaviors may hinder original interactions [4].

In mobile/pervasive AR, there are certainly a large number of collision situations where the user interaction could be unintendedly disturbed by the various environment, especially dynamic real objects that are not related to AR contents (e.g., passer-by, car) [4]. To address collision issues, the AR research has much focused on presenting physically plausible interactions (i.e., conflict-free) between virtual objects and real environments [6], but filmmakers and game developers have instead taken the approach to use special visual effects (VFX) for the audience to accept and tolerate such physically implausible situations. Inspired by the methods used in movies/games, we applied VFX on the VH's body when facing conflict situations instead of avoiding them.

To investigate the impacts of VFX applied to VHs in situations of collision with physical objects, we prepared a user study focusing on improving human perception. We measured the social/co-presence and physical abilities of VHs that can be reduced by physicality conflicts, as stated in previous work [5]. Furthermore, we looked into whether changes in the user perceptions toward VHs could have secondary effects on users' engaging or social behaviors. During the experiment, our VHs appeared in real space and demonstrated three conflict situations: (1) passing through a closed door, (2) parts of the body occupying the same volume with ROs while the VH was interacting with a user, and (3) a passer-by penetrating the VH. For each of these situations, we tested three types of VFX on VH's body parts that collide with ROs: (1) the body overlapped as is, (2) the overlapping body shown in faded-in/out effect, and (3) the overlapping body shown in flared-up effect (see Figure 1). We also included the condition of the situation in which no physical conflicts occurred at all. Our results indicate that VFX had significant effects on improving user perception for different situations and conflict types, but the user's behavior toward VHs was similarly observed. These findings would be an interesting view that no matter how users felt or thought about the VH, some VFX can be used to induce users to behave similarly in conflict situations.

This paper is organized as follows: Section 2 reviews previous studies. Section 3 describes a user study investigating the impacts of VFX in physicality conflict situations. Section 4 presents the findings, and Section 5 presents discussions and implications. Lastly, this paper concludes in Section 6.

II. RELATED WORK

A. PERCEPTUAL ISSUES WITH REAL OBJECTS IN AR

Several AR studies [10]–[12] reported that real-virtual interactions, in which VOs are affected by ROs or VOs affect ROs, are important for user perception of VOs. For example, Lee *et al.* [10] demonstrated subtle incidental movements of a shared real-virtual table increased social presence with VH. Kim *et al.* [11] reported that a virtual paper is fluttered by the real wind, and the VH's awareness of such event increased users' sense of co-presence in a shared space. Both VH's awareness and influence of users' physical space have shown positive effects. However, unintended mismatches in real-virtual interactions, or when VOs fail to act in response to ROs can cause perceptual issues. It is known that overlapping VOs and ROs make physically impossible situations (i.e., physicality conflict [5]) negatively affects social/co-presence.

To avoid collision, Norouzi *et al.* [6] presented VO's plausible behaviors in response to ROs (e.g., falling down by a pedestrian). However, we may not determine what the VO's correct behavior is, and such additional actions would make the awkward situation when a VH is apparently a virtual being, such as in OST AR [3]. Moreover, inevitable conflicts are rampant in most AR situations [4]. Thus, VHs might not be able to overcome the collision situations completely. Nevertheless, we considered that even in the collisions, the user's perception can be improved by VFX, and we propose manipulating visual rendering to study its effect on perception.

B. VISUAL EFFECTS ALTER OUR PERCEPTION

Several AR/VR studies [13]–[16] have shown the possibility of changing user perception by leveraging VFX as visual stimuli. Weir *et al.* [17] and Erickson *et al.* [18] presented that hot or cold VFX could influence the sense of the body temperature. They attached dynamic flames and icy fog on the user's hands or on the surrounding real environment to show them. Participants reported that they felt warm or cold in response to VFX even though they knew it was not real.

We consider that VFX can be applied even in these conflicting situations. Although VFX still needs to understand space, it may not require as much precision for plausible behaviors and it would be able to cope with most of the inevitable conflicts. For example, when a VH enters a closed door, it should be accompanied by works that open the door by a user [5], but VFX can simply be expressed in the collision part and then VH can pass through the door like a ghost. However, as Lee *et al.* [3] mentioned, VFX may have a negative effect by reminding them that VHs are not real, but we assume that physicality conflicts are greater negative factors and VFX might be acceptable.

C. VISUAL PERCEPTION IN PSYCHOLOGY

In psychology, it is well known that visual perception can alter human cognitive performance [19]. If multiple stimuli are presented simultaneously, visual stimuli dominate other stimuli, which is called visual dominance [20]. Similarly, visual salience [21], [22] is the distinct perceptual quality, making some of the ROs stand out from their neighbors and immediately catch users' attention.

Meanwhile, in advertising-related psychology, the wear-in/out effects are introduced concerning perceptual adaptation by repetitive visual stimuli [23]. Wear-in is a period during which users are gradually familiar with the new content [24]. Conversely, wear-out is to sensibly adapt content and rather feel bored due to repetition [25]. Thus, we considered that if we use familiar VFX through movies/games, users would consider VHs with VFX as acceptable. Moreover, we assumed that it would be new to see VHs overlap with ROs, which would be more awkward than VFX.

Considering the dominance and perceptual adaptation, we believe that VFX could alter the chances of perceiving events and the given events' perception. Thus, we applied VFX that are already familiar to people (i.e., acceptable) on collisions, investigating whether VFX could affect the user perception.

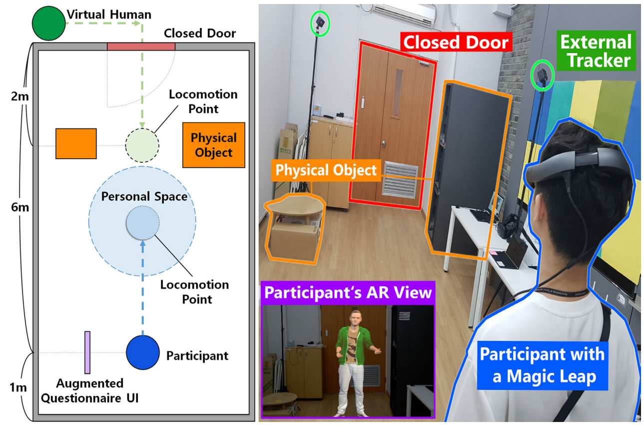


FIGURE 2. An experimental space where users experience scenarios in which our users interact with virtual humans in four conditions.

III. EXPERIMENT

A. PARTICIPANTS

For this study, we recruited 16 participants (male = 15, female = 1, aged 23-36, $M = 26.58$, $SD = 3.74$) from a local research institute. Most participants reported normal hearing and normal/corrected vision with glasses; five participants wore glasses. We asked participants to use a 5-point Likert scale (1 = Not at all, 5 = Very much) to rate their familiarity with VR ($M = 3$, $SD = 1.36$), AR ($M = 2.26$, $SD = 1.27$), and virtual human technology ($M = 2.06$, $SD = 1.33$).

B. MATERIALS

1) PHYSICAL SETUP

We designed the experimental room to simulate the collision situations between a VH and ROs during the interaction scenario (see Figure 2). There is only a closed door to enter the room, and this door has a transparent window that allows participants to look out the door (see Figure 1 (a)).

To simulate the collision with ROs, we placed the table and cabinet on each side of the room. The table is smaller than the VH's knee height, and the cabinet is larger than the VH's height. We also created a 3D spatial map in advance to support occlusion when a VH and ROs overlap. This map is the same as the room and contains static objects (e.g., door, table, cabinet). To consider the unexpected collision situations by passer-by, we attached a sensor on upper-body and it was tracked by external trackers. Thus, we received a 3D location of the passer-by through trackers to support occlusion.

When the experiment begins, the participant is about 6 meters away from the door. Then, VH walks from outside and stops about 2 meters away from the door. We defined the distance between participants and the VH as a public space [26]. This initial distance was set to investigate whether the participant's behavior was affected by VFX. We also prepared the survey UI in the AR to measure the social distance under the same conditions for all variables. For each condition, VHs asked participants to do the survey, which was

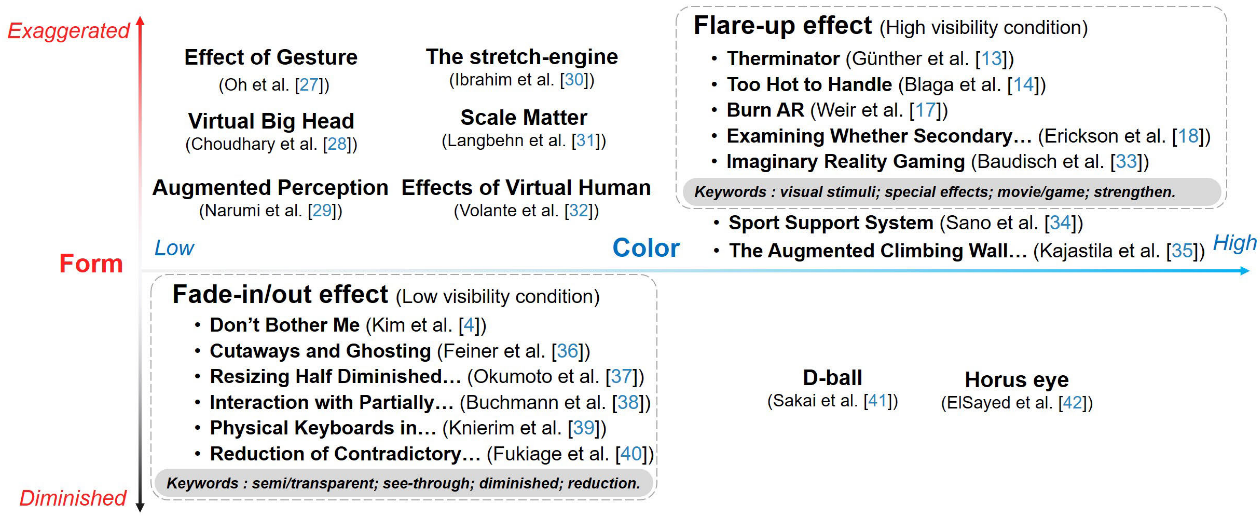


FIGURE 3. Visual effects taxonomy to be used in our experiment. We reviewed the previous AR/VR researches [4], [13], [14], [17], [18], [27]–[42] and classified color (Low, High) and form (Exaggerated, Diminished) as 2 × 2 matrices with respect to VFX's visibility.

designed to reset the distance narrowed to VH by previous conditions. Figure 2 shows more detailed information.

2) VISUAL EFFECTS CLASSIFICATION

To present VFX that can affect users' cognitive perception when a VH overlaps with physical objects or shows physically impossible behaviors, we explored visual perception in psychology. The human vision system can be divided into several components, including color and form [43], so we first considered the variations of colors and forms when designing the VFX. Moreover, as mentioned in Section 2.3, to exploit the impacts of visual dominance [20] by stimuli on human perception according to the saliency [21] of VFX, we set the intensity of VFX to either high-visibility or low-visibility. Therefore, we examined the colors and forms in detail to present each VFX's visibility clearly.

Color vision is widely known as subjective perception. However, thanks to numerous psychologists, it was gradually objectified [44], [45]. The color consists of hue, brightness, and saturation as the main properties. Hue is defined as a feature and subjective perception [46], and we adopted the CMYK color model [47] to select the base color for the VFX. To create low visibility VFX, we chose low saturation and brightness (i.e., black). On the contrary, to create a VFX with high visibility, we considered the Purkinje phenomenon in which blue-series colors are more visible in dark scenes [48]–[50]. Since we used the OST AR HMD, our environment would be slightly dark. Thus, we chose a cyan-color with a high intensity of saturation and brightness.

Concerning the VH's body form, we divided the VFX into exaggerated or diminished form. We considered the exaggerated form as high visibility, following Savignac's argument; unrealistic (or exaggerated) visual impacts can involuntarily attract attention and interest [51]. Conversely, for low visibility, we employed methods used in the field of diminished reality [52]. Diminished reality is a methodology of concealing, removing, or see-through the ROs to reduce the visibility of undesirable visual gaps between real and virtual scenes (e.g., incorrect occlusion, physical conflicts).

Based on our theory of VFX's visibility, we classified the numerous VFX that users are familiar with or are frequently used in previous AR/VR researches. Figure 3 is our VFX taxonomy, which is divided into color (Low, High) and form (diminished, exaggerated) as 2 × 2 matrices. We also present a set of keywords used for literature reviews. Among the numerous VFX, we confirmed that the fade-in/out and flare-up effects are commonly used in diminished and exaggerated forms, respectively. We then applied the black and cyan colors to create low and high visibility VFX to be used in our experiment. Therefore, we used a fade-in/out effect where black is applied and the body of the VH gradually diminished for low visibility VFX, and a flare-up effect that emits a cyan-color light from the body of the VH for high visibility VFX.

3) VIRTUAL HUMANS AND CONTROL

In our study, we used the Magic Leap, which is OST AR HMD, to display the VHs that exist together in our daily space. To provide interaction to participants, we prepared four VHs with the same visual embodied appearance as 3D male characters,[1] but have different names, voices, and jacket colors to help users distinguish their differences.

To make the participants feel immersed, we set the characteristics of VH in detail. Firstly, we used the human model with facial shape and SALSA lip-sync asset,[2] to ensure natural mouth movements and facial expressions when VHs talk to participants. Secondly, we instructed VH's eyes to stare at

[1] https://skfb.ly/6QTJ9

[2] https://crazyminnowstudio.com/unity-3d/lip-sync-salsa

the user as they speak. Thirdly, all of the VH's voice prompts were prerecorded by the Google Text-to-Speech,[3] and played back within the application. Fourthly, in our experimental scenario, VHs show some animations (e.g., idle, body gestures) from the Mixamo.[4] Lastly, we generated natural movements of VH's locomotion behavior using Final IK[5] such as walking through the door, wandering around the room while talking, and climbing onto the table.

During the experiment, we remotely controlled the predefined VH's dialogue and behavior outside of the room. Therefore, we implemented a client-server application that communicates wirelessly with the Magic Leap device. In order to run the scenario sequentially, we received the results as to whether the interaction was complete or not.

C. METHODS

We adopted a within-subjects design and users experienced all of the following conditions in a counter-balanced order:

- **NC** No collision with ROs
- **LO** Low visibility VFX (fade-in/out effect)
- **HI** High visibility VFX (flare-up effect)
- **CT** As a control condition, mere overlap

NC's VH recognizes the physical environment surrounding him. Thus, VH does not make irrational and unrealistic situations, so there is always collision-free. For example, the abnormal behavior of walking into the closed room or overlapping the surrounding furniture.

LO is intended to provide low visibility. We considered that physicality conflict would have an adverse impact on users because it aggravated physical rules [5]. Thus, we prepared fade-in/out VFX with low brightness/saturation, and diminished form. We then identified ROs that are predicted to conflict and expressing the VH's conflict part as VFX. Since the participants are wearing OST HMD, VHs look as if they are becoming transparent (see Figure 1 (b)).

HI is intended to provide high visibility. In the positive perspective that unrealistic conflict and VFX would have positive impacts on emphasizing VH's power and attracting users' attention. Thus, we implemented the flare-up VFX of emitting cyan-color light and changing VH's form to make a stand out the intersection point between the VH and physical objects (see Figure 1 (c)).

CT means our control condition for comparison with other conditions. CT's VH merely overlaps with physical objects without any VFX, i.e., it is a conventional representation of AR. VH understands the depth of ROs placed in physical space by known methods. Therefore, we support occlusion rendering, and participants can observe a reasonable VH's appearance. As describe earlier, however, these methods cause problems when ROs and VOs overlap. In this case, the portion of a VO that is farther than the RO is not visible, but the part of the VO that is close is visible to the user, creating an unreasonable situation (see Figure 1 (d)).

D. MEASURES

1) SUBJECTIVE MEASURES

At the end of each condition during the experiment, we asked the following questionnaire using a 7-point Likert scale.

- **Social presence**: We extracted questions from Bailenson *et al.* [53] to assess the extent of social presence for social entities perceived by VH.
  - *Q1: "I feel that the person in the room is watching me and is aware of my presence."*
  - *Q2: "The person appears to be sentient, conscious, and alive to me."*
  - *Q3: "Overall rate the degree to which you had a sense that there was another human with you, being interacting rather than just a machine?"*
- **Co-presence**: We used some of the questions from previous studies [54], [55] to measure the sense of being together with VH in the shared environment.
  - *Q4: "I perceive that I am in the presence of another person in the room with me."*
  - *Q5: "To what extent, if at all, did you have a sense of being with the other person?"*
  - *Q6: "How much did it seem as if the person you saw/heard had come to the place you were?"*
- **Physicality**: From previous studies [3], [56], we used several items to measure VH's physical perception that VH's physical influence and awareness.
  - *Q7: "I felt that the person was aware of the real environment."*
  - *Q8: "I felt that the person could affect the real environment."*
  - *Q9: "I felt the person could walk through me."*

In the post-experiment questionnaire, we requested the overall preferences of conditions and the preferred VFX in each physically impossible conflict situation, such as the closed-door, furniture, and pedestrian.

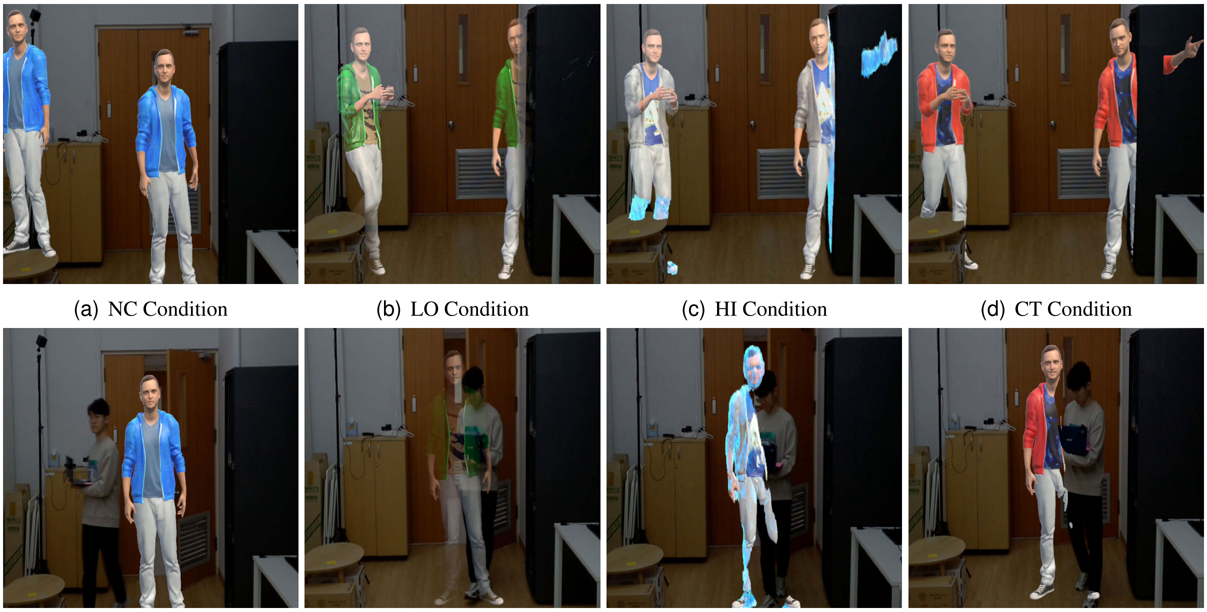
- **Preference**: *"Please select Rank 1, 2, 3, and 4 in the order of your preferred conditions." (Rank 1 - most preferred; Rank 4 - least preferred)*

2) BEHAVIORAL MEASURES

During the experiment, we extracted the participants' head position, orientation, and eye-gaze data using an eye-tracker embedded in Magic Leap device. We recorded all data every 20*ms* by Unity's fixed-update function and organized the following measures:

- **Observation Ratio**: The ratio is the time devoted to looking at the body of the VH. We divided the VH body into three parts: head-torso, arms, and legs.
- **Proxemics and locomotion behavior**
  - Minimum distance: It is from VH to the participant who stopped walking. If the distance is relatively

[3] https://cloud.google.com/text-to-speech
[4] https://www.mixamo.com
[5] http://root-motion.com



(a) NC Condition (b) LO Condition (c) HI Condition (d) CT Condition

(e) NC Condition (f) LO Condition (g) HI Condition (h) CT Condition

FIGURE 4. Photograph of each condition of our interaction scenario. Step 2 (a-d): Collision with surrounding furniture while VH is roaming around the room. Step 3 (e-h): a pedestrian cross the VH while a VH is talking with a participant.

large, it means that participants consider VH as a social entity and maintain their personal space.

- Walking speed: The average speed at which participants walked the same path under each condition.
- Walking trajectory: The path where participants approach a VH and return to original location.

E. PROCEDURE

At first, we briefly described the study and protocol to the participants. Participants then wore OST AR HMD on their heads as instructed. We also provided a simple game for participants to become familiar with the HMD and controllers. During the game, participants adjusted their wearing styles to make them feel comfortable and see more content. Then, we remotely terminated the game and launched our experimental system. Once our system is loaded, spatial maps are augmented into a predefined location firstly.

Before starting the study, we instructed the participant to see the augmented UI in the left 90° direction (see Figure 2). It included the experimental procedure and training system on how to use the controller to answer questions with 7-point scales. While the participant was in training, the experimenter left the room and waited for the completed training procedure. Upon receiving a message remotely that the participant has completed the training, the experimenter sequentially executed VH's interaction steps 0 to 5.

1) INTERACTION SCENARIO

We prepared interaction scenarios between a user and VHs consisting of 6 steps.

Step 0 – Preparation: Except for a NC condition (i.e., LO, HI, CT), VHs violate physical rules, so VH is augmented outside the room for collision with the closed-door. However, NC's VH should not appear suddenly or pass through a closed door because it must comply with physical rules. Thus we remotely augmented a NC's VH in the room when a participant was looking in different directions to fill out the questionnaire or train the UI.

Step 1 – VH passes through the door: Since the door of our room is closed, participants can only observe VHs approaching the room through the window (see Figure 1 (a)). When the VH passes through a closed door, parts of the VH body farther from the door are occluded by the door. Additionally, in the LO and HI conditions, we express the VFX at the intersection of the VH (see Figure 1 (b, c)). As the VH pass through the intersection of the door, the VFX disappears, and the normal appearance of VH is seen (see Figure 1 (d)). Then, when VH arrives at its destination, VH stops walking and starts talking to the participant with gestures.

Step 2 – VH passes through the furniture: When this phase begins, VH roams around the room and reads the script. At this time, VH collides with furniture (i.e., table, cabinet). It should be noted that collisions with static objects can be avoided and provide plausible behavior. For this consideration, NC's VH stepped on the table and stopped walking in front of the cabinet to avoid the collision with a plausible way (see Figure 4 (a)). However, under other conditions, the VFX was applied to the intersection of collision with ROs, as like step 1. When VHs collided with the cabinet, VFX was expressed in the left half of the VH's body part. In the case of the table, VFX was expressed on the leg side of the VH where the collision occurred (see Figure 4 (b, c, d)).

Step 3 – passerby passes through the VH: While VH is talking to the participant, a pedestrian crosses the space occupied by VH. This situation, which collides with unexpected dynamic objects, is an inevitable collision. For the study, we used the external tracker to track the pedestrian's location, and support occlusion and VFX (see Figure 4 (f, g, h)). In NC condition, however, the pedestrian intentionally passed sideways (see Figure 4 (e)).

Step 4 – Participant approaches the VH: To explore the social distance between VHs and participants. VHs ask participants to come forward to observe their appearance. When the participant stopped approaching any more, we executed the next step.

Step 5 – VH passes through the door to leave the room: Unlike Step 1, participants can observe a gradual occurrence of VFX. Then, when VHs completely passed the door, participants can see a normal-looking VH through the window. For NC, when participants look in different directions for the survey, we remove a VH remotely.

At the end of each condition, participants answered our questions using augmented questionnaires while wearing HMD. The survey results were immediately stored in the device's local storage. When all conditions are finished, participants removed the HMD and answered a post-questionnaire consisting of condition preferences (overall, each situation). Lastly, we asked participants to leave the comment and had a short interview for the experiment.

F. HYPOTHESES

We formulated our hypotheses as follows:

H1 Social Presence and Co-Presence ratings will be higher in lower visibility of the physicality conflict representation (Expected result: LO > CT > HI).

H2 Physical abilities will be higher when there is the visual changes or less visibility in response to the conflicts (Expected result: LO ≥ HI > CT).

H3 Participants will report their preferred VFX differently depending on the conflict situations (i.e., Collision avoidance possible, or not).

H3a Expected result of avoidable types: NC > LO > CT ≥ HI

H3b Expected result of inevitable types: NC ≥ HI ≥ LO > CT

H4 Participants will allocate more attention behavior with higher visibility for physically implausible events (Expected result: HI > CT ≥ LO).

H5 When VHs maintain their presence using VFX, Participants will exhibit more keeping social distance (Expected result: NC > LO ≥ HI ≥ CT).

IV. RESULTS

A. SUBJECTIVE MEASURES

Concerning the reliability of our questionnaire items, we calculated Cronbach's alpha for each category of measure. For user's preference rankings of conditions, we also analyze

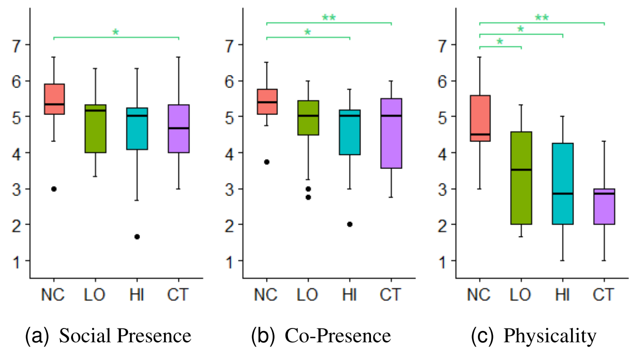


FIGURE 5. Results of subjective measure (* $p < .05$; ** $p < .01$; *** $p < .001$).

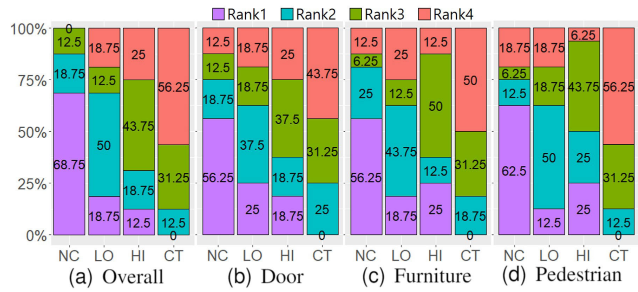


FIGURE 6. Preference rankings of VFX for overall and each conflict scenario (Rank 1-most preferred; Rank 4-least preferred).

each ranking data separately. Considering our study design and the ordinal scales of subjective measures, we chose to perform non-parametric Friedman tests. For the pairwise comparisons, we performed Wilcoxon signed-rank tests with Bonferroni adjustment (both at the 5% significance level). The results are summarized in Figure 5, 6 and Table 1, 2.

1) SOCIAL PRESENCE

We found a significant main effect of the condition on Social Presence ($\chi^2 = 8.57, p = .033$). Post-hoc tests revealed that CT was significantly lower than the score of NC ($p = .039$), indicating that an additional VFX in collision situations could alter the perceived social aspects of the VH; however, we did not find any significant differences in other pairs.

2) CO-PRESENCE

A significant main effect on Co-Presence was also found ($\chi^2 = 17.5$, $p < .001$). Post-hoc tests showed there were significant differences between NC and CT conditions ($p = .009$), and between NC and HI conditions ($p = .036$). Again this indicates that the additional VFX can change users' subjective feelings of being with a VH. For all other pairs, there were no significant differences.

3) PHYSICALITY

We found a significant main effect of the condition on Physicality ($\chi^2 = 22.9$, $p < .001$). Post-hoc tests showed there were significant differences between NC and CT conditions ($p = .006$), NC and HI conditions ($p = .02$), and NC and LO conditions ($p = .018$). Again this indicates that VFX can

TABLE 1. Analysis results on the subjective measures.

Measure	Cronbach	Friedman	Post-hoc
Social Presence	$\alpha = .93$	$\chi^2 = 8.57, \ p < .05$	NC>CT*
Co-presence	$\alpha = .92$	$\chi^2 = 17.5, \ p < .001$	NC>CT** NC>HI*
Physicality	$\alpha = .75$	$\chi^2 = 22.9, \ p < .001$	NC>CT** NC>HI* NC>LO*

Statistical significance levels: * $p < .05$; ** $p < .01$; *** $p < .001$

TABLE 2. Summary of the results on preference rankings.

Conflict types	Friedman	Post-hoc
Overall	$\chi^2 = 17.96, p < .001$	NC > HI*; NC > CT***
Door	$\chi^2 = 7.720, p > .05$	
Furniture	$\chi^2 = 9.720, p < .05$	NC > CT*
Pedestrian	$\chi^2 = 11.40, p < .01$	NC > CT**

Statistical significance levels: * $p < .05$; ** $p < .01$; *** $p < .001$

improve VH's physical abilities (e.g., awareness, influence). We did not find a significant difference in other pairs.

4) PREFERENCE

In all scenarios, NC was the most preferred condition, while CT was the least preferred one (see Figure 6). However, our analysis of the rankings revealed that there was no significant difference between conditions for how the VH entered the room. Results for Friedman tests and pairwise comparisons are summarized in Table 2. While we did not find any significant differences between LO and HI on users' preference, post-hoc tests on overall preference rankings revealed only HI condition among the two VFX was significantly less preferred compared to NC.

B. BEHAVIORAL MEASURES

Due to technical glitches in our data logging system, we had to remove data from three participants. Thus, a total of 13 participants' data is used in behavior analysis. Considering the small sample size, we again performed the non-parametric Friedman tests on behavioral measures. We used data collected during Step 2 for observation behavior analysis and data collected during Step 4 for proxemics and locomotion behavior analysis. In summary, we did not find any difference in users' gaze and social distance behavior between conditions except gaze duration on the VH's hands during the Step 2. However, there are tendencies that participants observed the body parts of the VH more in HI compared to LO.

1) OBSERVATION BEHAVIOR

We extracted the names of VH's body parts on which participants looked at each frame, using the embedded eye tracker in the Magic Leap device. We grouped the body parts into three categories: head+torso, arms, and legs, and calculated the time participants spent looking at each category of VH's body. To compensate for the slight difference in the duration of Step 2 per each participant, we divided the time by the entire duration of Step 2, making it a ratio measure instead of time measure. We also separately calculated the dwell time ratio on each category of VH's body per onset for each physicality conflict type. Because the VH in NC condition did not collide with ROs in Step 2, we excluded when comparing data for the onset of physicality conflicts only.

Friedman tests performed on observation ratio data during the entire Step 2 showed a significant main effect of conditions on the observation ratio on VH's hands. However, post-hoc pairwise comparisons did not find any significant differences between all pairs. All other Friedman test results are summarized in Table 3.

TABLE 3. Summary of the Friedman test results on observation ratios for Step 2 overall, and when virtual human was colliding with real objects.

Range	Head+Torso		Arms		Legs	
	χ^2	p	χ^2	p	χ^2	p
Overall	1.89	.59	7.98	< .05	.78	.85
Table	2.00	.37	2.00	.37	1.85	.40
Cabinet	0.73	.70	1.44	.49	1.55	.46

2) PROXEMICS AND LOCOMOTION BEHAVIOR

In Step 4, VHs asked participants to walk toward and stand at a comfortable area to observe the VH. During the task, we logged their positions for every 20 ms. We calculated the minimum distances between participants and the VH. We also measured the average speed when participants were approaching the VH. Considering the acceleration, we used position data between from 3.5m to 1.5m away from the VH.

Figure 8 shows the results. We did not find any significant effects of conditions on the minimum distance ($\chi^2 = 6.415$, $p < .093$) and walking speed ($\chi^2 = .231$, $p < .973$). While, in HI condition, participants kept slightly shorter distance compared to those of HI and CT conditions, it did not reach statistical significance. It should be noted that, in all conditions, participants invaded VHs personal space (about $1.2m$), walked slower than normal speed ($1.4m/s$) and walked on the slight same trajectory (see Figure 9).

V. DISCUSSION

Overall, our results show that VFX for physically implausible situations in AR affect users' sense of social/co-presence as well as the perceived physical abilities of the VH. However, the participants' preference for the VFX seemed to depend on the type of situation. While the most preferred condition was the NC, the LO (fade-in/out) was the most preferred among the conditions with physicality conflicts. However, despite the change in the users' perception of VHs, users' behaviors (i.e., proxemics, gaze) did not change. For these results, we believe that VFX has the potential (or secondary effects) to induce the same user's behavior when interacting with VHs, which have different features (i.e., presence, physicality). In the following, we discuss the results in-depth and provide potential explanations and implications.

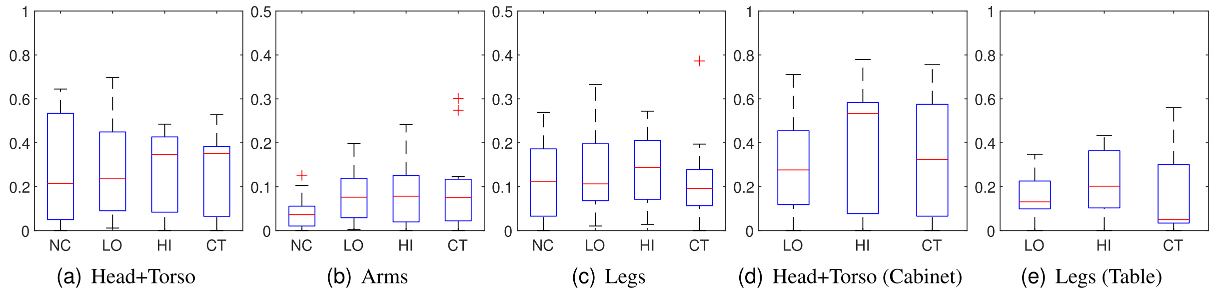


FIGURE 7. Observation ratio results: (a) Head+Torso, (b) Arms, (c) Legs, (d) Head+Torso(Cabinet), and (e) Legs(Table).

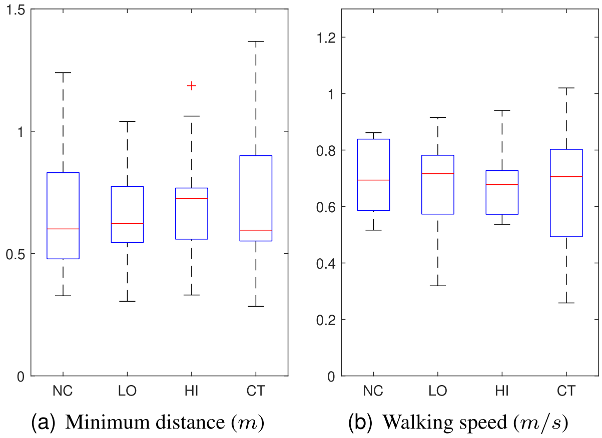


FIGURE 8. Results of proxemics and locomotion behavior.

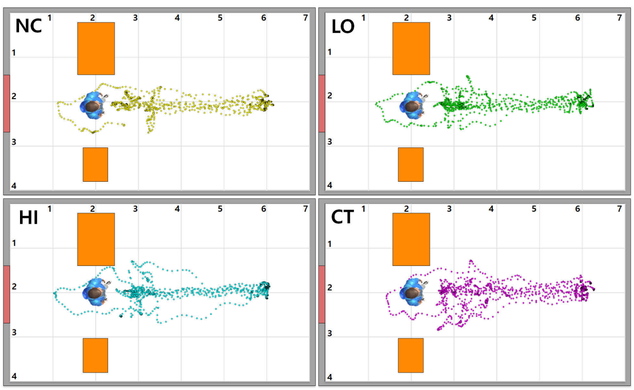


FIGURE 9. Participant's walking trajectories during step 4 for each condition.

A. VISUAL EFFECTS HELP MAINTAIN SOCIAL/Co-PRESENCE IN COLLISION SITUATIONS

We thought that moment-by-moment visual transformation in part of the VH's body *alone* would likely have negative effects, and especially the VFX with high visibility would remind users that VHs are virtual entities. However, if the VFX worked in a way that makes collision less noticeable (e.g., fade-in/out as LO), it can also have positive effects on users' perception of the VH. Given that conflicts in AR can reduce users' perception [4]–[6], we assumed that the frequency of noticeable collision would have a stronger negative effect than the momentary VFX on VH's body. Thus, we expected the rating of LO > CT > HI (as H1).

Although we did not found statistical differences between the conditions under which the collision occurs (i.e., LO, HI, and CT), we found that NC has a significantly higher social presence than CT (see Figure 5 (a)). Occlusion, avoidance, and plausible behaviors used in NC conditions are well-known solutions to make collisions less noticeable [5], [6], so our participants would not have noticed collisions in NC conditions. In addition to this, we argue that VFX can also be included in the solution. Our results show that the VFX conditions (LO, HI) are statistically similar to either NC or CT, but their mean value is close to NC and larger than CT. This implies the possibility of improving social presence through VFX rather than leaving the conflict as it is.

These arguments can be supported by the results of co-presence (see Figure 5 (b)). Our participants rated two-levels higher co-presence in NC than CT. We also found that participants rated NC one level higher than HI. However, we did not find any statistical difference between NC and LO. With this, we may expect the VFX to help maintain a sense of presence compared to CT. Although HI decreased compared to LO, we believe that high visibility VFX reminded users that VHs are not real as we expected. Regarding our argument, we share the participant's comment.

> *P15: "HI and CT look fake. We can recognize easily that they are 'machine'. On the other hand, NC looks so real and not like a ghost. For LO, it looks real. However, LO looks like a ghost".*

As the P15 said, CT and HI felt like machines, so it would be difficult to expect high social/co-presence from VHs. In the case of LO, our participants could be perceived the VHs as real, but it would be looked like a ghost because the VH passed through the real objects. Thus, LO would be received a lower rating than NC. From our results, we believe that VFX served as a plausible alternative in inevitable collisions and as an additional effect to help users tolerate and accept awkward situations. Although LO's presence is not as high as NC, which is considered the best way, there are many conflicts with physical objects in our daily lives, and we cannot guarantee that VHs can always avoid collision situations. In this respect, we can consider that VFX is influential and should be used to maintain the social/co-presence, which can be reduced by physical collisions, as in CT.

B. VISUAL EFFECTS CAN BE AN ALTERNATIVE TO PLAUSIBLE BEHAVIOR TO IMPROVE PHYSICALITY

We hypothesized that VHs would have high physical abilities if they responded to conflict situations (as H2). In our results, NC shows a statistically higher physicality compared to all other conditions (see Figure 5 (c)), because NC's VH showed the plausible behaviors in response to the collision. Thus, participants would have been thought that VH was aware of the physical environment and could affect the physical objects.

> *P5 : "The NC's VH that could interact and aware of physical environment is more closer to reality"*
> *P11: "NC was walking on the table, it seemed like he is aware of that physical object he approaches"*

Although there are no statistical differences between the other conditions, the VFX seems to improve perceived physicality in LO, HI compared to the CT condition. This might be because the VFX has become an alternative to plausible behavior in response to physicality conflicts.

> *P2: "The man interacted well with the environment using effect and seems aware the obstacles nearby."*
> *P4: "I felt that he was aware of something because of the effect when it collided with objects."*

In our daily space (e.g., home, office), there are certainly many situations in which VHs cannot respond to conflicts with physical objects or intrusions by dynamic objects, as we have shown in our experiments (e.g., closed-door, passerby). We also consider that supporting plausible behavior to avoid these inevitable conflicts can be rather a negative factor that distracts interaction with VHs. For example, to avoid collisions with pedestrians, VHs need to move constantly, but avoidance movements are not related to the original interaction, which can be distracting factors [4]. Therefore, if it is necessary to improve the VH's physicality in our daily space, we believe that VFX can be an alternative to reducing the perceptual issues caused by conflicts rather than plausible behaviors that react one by one to physical conflicts.

C. VISUAL EFFECTS MIGHT BE REQUIRED FOR THE TYPE OF CONFLICT

We considered the visual saliency of the physicality conflict events as well as the logical necessity of the additional VFX. By logical necessity, we mean whether the physicality conflict is avoidable or inevitable situations. As described in Section I, for the VH to enter the room with a closed door, physicality conflict is inevitable, the same for the pedestrian unaware of the position of the VH. On the other hand, collisions with static objects (e.g., table, cabinet) seem avoidable situations. Therefore, for the avoidable cases, we hypothesized that it would be better for the user to be unaware of such conflict situations (as H3a). On the contrary, for inevitable cases, an additional explanatory effect might help users take them as plausible alternatives (as H3b).

As for user preference, there were statistically significant differences in favor of the NC condition (see Table 1). There was no statistical difference between LO and HI in relation to logical conflict situations, but participants' preferences showed similar aspects (see Figure 6). None of the participants preferred CT conditions first, and they commented that CT was unnatural. Nevertheless, VFX conditions are sometimes preferred first, and LO received more votes than HI. In overall preference, the LO condition was the second preferred by more than half the participants. Participants who preferred LO usually commented that they were realistic and comfortable with their eyes. We share some comments by our participants who preferred HI over LO.

> *P1: "I chose HI's VH because of their 'interest' and 'enjoyment' rather than 'reality'."*
> *P3: "When he passes through the door or walked through by real person, dazzle effect seems more real to me. It emphasis the mind that the person is still there instead of becoming trans- parent/darkened."*

Our findings might indicate that it is better to use VFX rather than leave the VHs in physicality conflicts. From the unnaturalness of collision situations, users can feel realistic or comfortable with fade-in/out effects as well as enjoyment with flare-up effects. However, differences in preference for logical conflict situations (i.e., avoidable vs. inevitable) depend on visibility require further investigation.

D. VISUAL EFFECTS CAN INDUCE SIMILAR USER BEHAVIORS IN CONFLICT SITUATIONS

When we designed study, we hypothesized that if the user's perception of VH was changed by VFX, the user's behavior would also be affected. We believed that these impacts could be considered as VFX's secondary effects. For the gaze behavior, we assumed that the conflict events would catch users' attention and that the level of the VFX's saliency would modulate the chances of noticing such events (as H4). Concerning the proxemics, we expected that users would slowly narrow the social distance from a VH when users highly perceived the social/co-presence of a VH (as H5).

As a result of analyzing user behavior, our hypotheses were not supported. In comparison between NC and others, we found a significant difference in participants' gaze allocation on arms, but not enough to support our hypothesis. Moreover, in the case of proxemics, participants in all conditions had almost a similar social distance, approached a VH at a similar speed, and showed similar behavioral trajectories. We confirmed that users acted similarly to VHs under all conditions even though their perception of VHs was changed. However, we believe that these results are interesting aspects and further emphasize the need to use VFX in collision situations.

As in previous studies [3], [6], changes in the user perception can affect the user's behavior as well, which has been considered a natural advantage. However, we should note that physical conflict is an unintended factor and distracts the original content. To handle content-irrelevant (or unintended) collision events, we can provide users with VH's plausible behaviors in response to the collision, but we have to prepare VH's behavior to respond to changing or unexpected user's behaviors. If the intended interaction does not work properly due to the user's changed behavior, it can have a negative impact on the user's experience. For example, if there is a specific location where the user should be located, otherwise the content may be delayed or VH may interact in the air. Therefore, it needs to be reminded that the methods proposed in previous studies may not be the best solution. Nevertheless, VFX can reduce perceptual issues caused by physicality conflicts as well as can induce users to behave the same way. Thus, VFX may help users interact correctly without perceptual awkwardness, leading to greater user experience improvements. However, further investigation is required.

VI. CONCLUSION

In this paper, we presented a user study that was conducted to investigate the impacts of VFX applied to VH's body parts in situations where a VH and physical objects collide. We expected that VFX would make physicality conflicts less noticeable and address perceptual issues with a VH. We prepared four types of VH and three collision situations that we can face when interacting with VH in our daily lives. Then we measured the social/co-presence and physicality that users subjectively perceive from VHs. We also expected and observed that if the user's perception of VH changes, there will be a secondary effect that influences the user's behavior toward VHs.

Our results indicate that VFX was able to make conflicts between virtual and physical objects less noticeable. This resulted in VFX having a positive impact on maintaining VH's social/co-presence in physicality conflicts that could adversely affect user perception. Also, the VH's physical ability significantly improved due to VFX in response to conflicts with physical objects. However, there was a difference in VFX, so we prepared LO as low visibility VFX and HI as high visibility VFX, in line with the taxonomy for VFX we proposed. Although it is difficult to conclude a more preferred VFX in relation to the specific conflict types we presented, each VFX has valuable benefits. LO had the advantage of making VH look comfortable and realistic to users, and HO had the disadvantage of reminding users that VHs were not real, but it could be interesting and entertaining to users. Furthermore, we presented the limitations that VFX induce the user's behavior similarly, but we noted an interesting view. To make seamless interactions with VHs, the user's behavior may need to be controlled and induced in part. However, if the user's behavior is unpredictable due to the perception changes, this may lead to poor interaction and negatively affect the user experience. From our point of view that perceptual issues arising from physicality conflicts should be improved and the user should behave the same way, we believe that VFX may be helpful because VFX may induce the user's behavior equally.

We first addressed the *'inevitable'* conflict between virtual and real objects and proposed VFX as a solution. To examine the impacts on VFX, we organized the taxonomy for VFX used in AR/VR domains and discussed the study results regarding the users' perception and behavior. We believe that VFX can diminish perceptual issues caused by physical collisions in AR and that our findings have valuable contributions to pervasive/daily AR. In future work, we plan to extend our study to using VFX in various scenes because there are more physically impossible situations when participants walk somewhere with VHs. We also plan to explore other VFX cues to generalize our study. With regard to the secondary effect on user behavior, using scenarios involving multiple more dynamic physical-interactions would provide more valuable and useful insights.

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