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The effects of virtual human's spatial and behavioral coherence with physical objects on social presence in AR

Kangsoo Kim[1] | Divine Maloney[2] | Gerd Bruder[1] | Jeremy N. Bailenson[3] | Gregory F. Welch[1]

[1]Department of Computer Science, University of Central Florida, Orlando, FL, USA
[2]Sewanee: The University of the South, Sewanee, TN, USA
[3]Department of Communication, Stanford University, Stanford, CA, USA

Correspondence
Kangsoo Kim, Department of Computer Science, University of Central Florida, Orlando, FL, USA.
Email: kskim@knights.ucf.edu

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Abstract

In augmented reality, people can feel the illusion of virtual humans (VHs) integrated into a real (physical) space. However, affordances of the real world and virtual contents might conflict, for example, when the VHs and real objects "collide" by occupying the same space. This implausible conflict can cause a break in presence in real–virtual human interactions. In this paper, we address an effort to avoid this conflict by maintaining the VH's spatial and behavioral coherence with respect to the physical objects or events (e.g., natural occlusions and appropriate help-requesting behaviors to avoid implausible physical–virtual collisions). We present a human subject experiment examining the effects of the physical–virtual coherence on human perceptions, such as social/copresence and behaviors with the VH. The basic ideas, experimental design, and results supporting the benefit of the VH's spatial and behavioral coherence are presented and discussed.

KEYWORDS
augmented reality, copresence, physical–virtual coherence, social presence, virtual human

1 | INTRODUCTION

The social influence of a virtual human (VH) on real humans has been studied in various social contexts involving real–virtual human interactions. The mediator for social influence could be "social/copresence"—the sense of "being socially connected/together."[1] While there is debate about the precise definitions for social/copresence, Blascovich et al. define social presence both as a "psychological state in which the individual perceives himself or herself as existing within an interpersonal environment" and "the degree to which one believes that he or she is in the presence of, and dynamically interacting with, other veritable human beings."[2,3] Given the definitions related to social interactions and interpersonal environments, social/copresence could be highly influenced by the plausibility of the social context where the interactions happen.

Regarding the (social) plausibility in real–virtual human interactions, specifically in an augmented reality (AR) environment, in this paper, we present an experiment to examine the effects of spatial and behavioral coherence between a VH and the surrounding physical objects on the sense of social/copresence and human behaviors. Spatial coherence can be exemplified by a VH's natural occlusions with physical objects (or vice versa), which can maintain the visual plausibility in AR, where virtual and physical or real contents are mixed in a colocated shared space. Thus, for the spatial coherence variation in the experiment, we adjusted the VH's body either naturally occluded or not occluded at all by the physical objects, such as a table and a chair. Behavioral coherence can be a VH's awareness of physical objects or events in the environment and appropriate behaviors towards them for the plausibility in the social context. In our experiment, we situated a physical–virtual conflict that the VH had to overcome. A physical obstacle, a chair, was located on the way to the VH's locomotion target (see Figure 1). In this situation, the VH may choose different behaviors to deal with the conflict—either requesting help from the participant to move the chair or passing "through" the physical

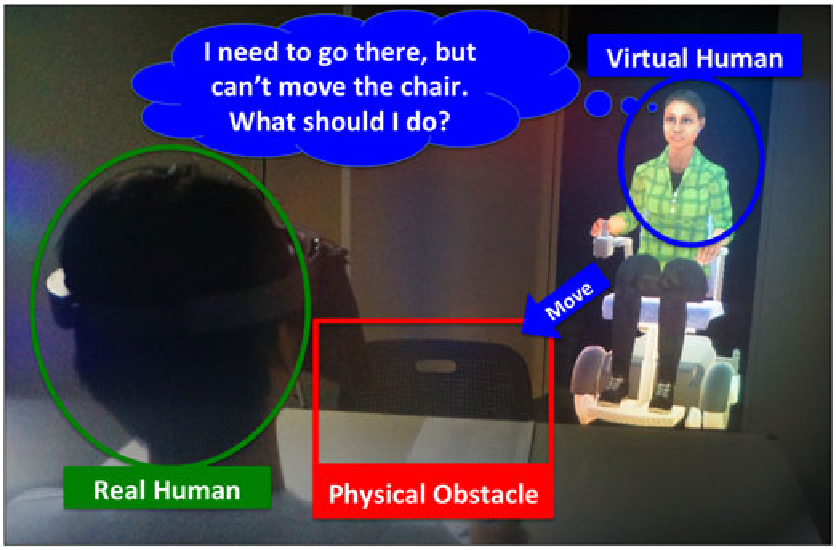

FIGURE 1 An example of a spatial and behavioral coherence problem in augmented reality. A virtual human needs to go to the space where a physical chair is already occupying

chair in a ghost-like fashion because the VH cannot physically manipulate the chair.[4] Human participants' perceived social/copresence and behavioral dynamics with the VH were analyzed through both subjective questionnaires and objective behavioral data. The analysis revealed positive effects of the VH's plausible appearance and behavior on the sense of social/copresence with the VH. We discuss the qualitative and quantitative results, consider potential limitations and unknown effects, and outline guidelines for practitioners in the field of AR.

This paper is structured as follows: Section 2 gives an overview of related work on VH research examining social influence, such as social/copresence and behavioral influences. Section 3 presents the experiment that we conducted to investigate the effects of spatial and behavioral coherence on VH's social influence. Section 4 shows the results, which are discussed in Section 5. Section 6 concludes the paper.

2 | RELATED WORK

Virtual humans have been popularly employed in various scenarios, and (social) experiences with VHs could influence one's behaviors during the interaction with the VHs, and even after the interaction. Here, we explore previous works dealing with social influence of VHs and describe research examples of VHs in AR and aspects of physical–virtual plausibility with spatial and behavioral coherence.

2.1 | Social influence of virtual humans

The social influence of VHs on real humans has been studied in different contexts with various measures—both subjective ratings and objective behavioral/cognitive measures.[5] For example, Park and Catrambone[6] demonstrated the social facilitation theory using a VH, that is, that one performs simple tasks better and complex tasks worse when in the presence of a VH. Guadagno et al.[7] investigated the role of a VH's gender and behavioral realism in persuasion and found that the VH was more persuasive when it had the same gender as the user, and exhibited greater behavioral realism. Bailenson et al. showed evidence supporting the equilibrium theory, that is, that mutual gaze and proxemic behavior are inversely related to each other. They found that people maintained more space around VHs than non-human-like virtual objects.[8]

To the best of our knowledge, however, there are few or no studies about the effects of VH's spatial and behavioral coherence (ie, natural occlusions and behaviors avoiding implausible physical–virtual conflict) on social/copresence with (or social influence of) VHs, particularly in AR.

2.2 | Virtual humans and physical–virtual plausibility in AR

Relatively few research publications about human perception and behavior with VHs in AR exist, compared to studies and results in VR and typical projection-based mixed reality (MR). Jo et al.[9] developed an AR telepresence framework using a virtual avatar in AR controlled by a remote user and discussed how to maintain the avatar's realism in the physical local place by adapting its motion to the surrounding physical objects. Holz et al.[10] surveyed various forms of agents in a fully physical, a fully virtual, or an MR environment in the context of social interaction, and detailed the advantages and issues with social interaction with MR agents. All these examples directly or indirectly addressed the importance of

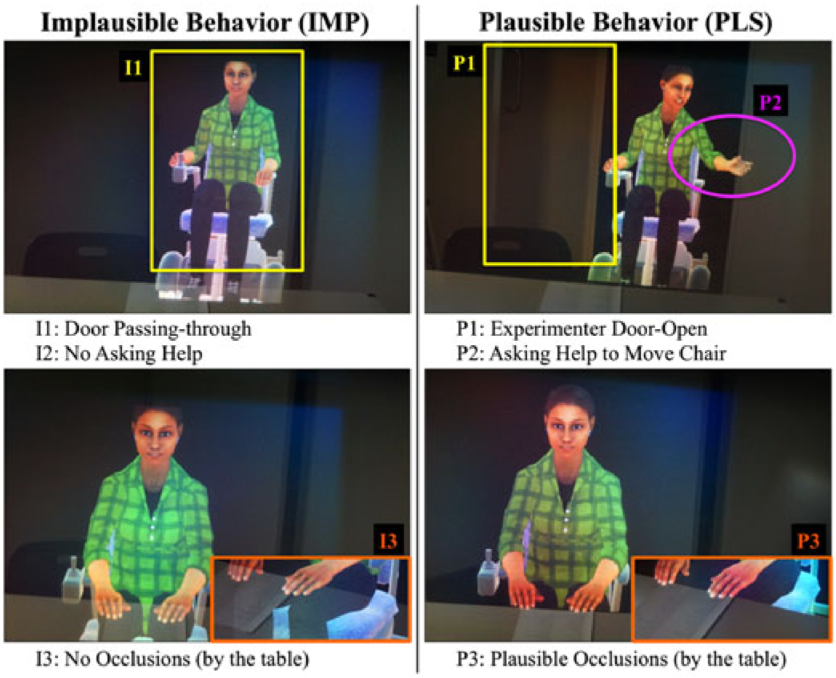

FIGURE 2 Study groups: the IMP group (left) and the PLS group (right)

plausibility/coherence between the virtual humans and the physical–virtual shared environment.

In AR environments, maintaining plausibility in the shared physical–virtual space via spatial and behavioral coherence could be intuitively important in human perceptions of the virtual contents. In that sense, AR researchers tried to achieve convincing occlusions between physical and virtual objects or humans. For example, in a collaborative AR environment, Fuhrmann et al. suggested methods to reduce irritating visual artifacts among virtual objects and a real human user's tracked body or real objects.[11] Microsoft Developer guidelines for HoloLens "Spatial Mapping"[12] reinforce the need for plausible real–virtual relationships and interactions, for objects and humans.

3 | EXPERIMENT

In this section, we detail our experiment to analyze social/copresence and human behavior in the presence of conflict situations related to spatial and behavioral coherence in AR (see Section 1). We describe the traditional situation in AR with spatial conflicts that can lead to implausible behavior when interacting with VHs. We introduce a range of behaviors of a VH that can be regarded as plausible in the AR context and have the benefit of avoiding physical–virtual collision (i.e., dual occupancy in the same place). In particular, the VH's behavior to ask for help from real humans can overcome a VH's lack of ability to control the physical objects.

3.1 | Study design

To evaluate the effects of a VH's spatial and behavioral coherence with physical objects in AR, the experiment used a between-groups design with two different groups: the "implausible behavior" (IMP) group without spatial and behavioral coherence (Figure 2, left), and the "plausible behavior" (PLS) group with coherence (Figure 2, right) as described below. Participants were randomly assigned to one of the two groups and interacted with a VH in an AR environment.

- **Implausible behavior (IMP)**:
  - **I1**: The VH ***passes through the door*** without opening it.
  - **I2**: The VH does ***not ask for any help*** from the participants and does not avoid physical-virtual collisions.
  - **I3**: The VH is ***not occluded*** by the physical objects.
- **Plausible behavior (PLS)**:
  - **P1**: The experimenter ***opens the door*** when the VH enters/leaves the room.
  - **P2**: The VH ***asks the participant to move the chair*** out of the way for her to get to the table without an implausible physical-virtual collision.
  - **P3**: The VH is ***occluded*** by the physical objects.

3.2 | Material

3.2.1 | Virtual human and human controller

We created a VH, called "Katie," that could perform facial expressions, speech, and body gestures. To preserve the

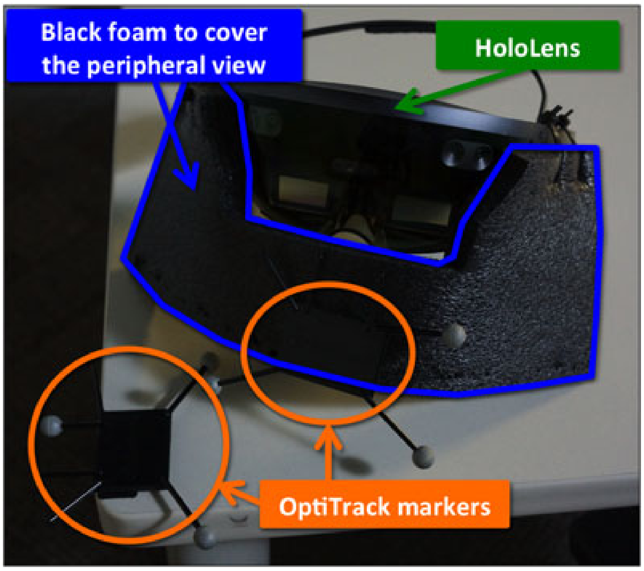

FIGURE 3 Microsoft HoloLens with the partially covered face. The OptiTrack markers were used to track the pose of the participant

plausibility of a request for help, we positioned the VH in a virtual electric wheelchair, that is, she appeared to be physically challenged and never stood up during the experiment (see Figure 2). The VH was displayed through a head-mounted display, Microsoft HoloLens (see Figure 3). The VH was remotely controlled by a real human behind the scene using a graphical user interface to trigger the VH's predefined speech and behavioral animations. Thus, we implemented a client-server application communicating between the HoloLens and the control workstation wirelessly. The VH's voice had a spatial audio effect; hence, participants could feel the localized sound from the VH. Throughout the interaction, the VH exhibited neutral or slightly pleasant facial expressions and sometimes looked down at the paper on the table.

One problem we encountered with the HoloLens was its narrow field of view. Because the screen on the device projecting the VH was small and the HoloLens allowed participants to see the real environment even in the periphery of their eyes, the VH's body would disappear when the participants were changing their view direction. This limitation of the current-state AR display hardware could possibly cause a severe distraction or break in presence for participants, in particular regarding the interaction with the VH in our scenario. Therefore, we partially covered the front of the HoloLens with a black polyether foam so that participants could concentrate on the VH in front of them while the peripheral view was reduced, that is, minimizing cropping or disappearing errors.

3.2.2 | Physical environment and recordings

We furnished the physical experimental room with a table, a box-like blocker, and two chairs (see Figure 4). The room had two doors on its opposite sides, and the table was in the middle of the room at a tilted angle (about 45 degrees) with chairs on opposite sides of it. The participant was instructed to sit on the chair close to the wall, after which, the VH entered the room and moved with the wheelchair to the opposite side of the table. To log the participant's movement trajectory in the room, we used ten OptiTrack cameras and two markers (one on the HoloLens and the other on the table; see Figure 3).

3.3 | Methods

3.3.1 | Interaction scenario

After sitting down on the chair at the table in the laboratory room, participants interacted with the VH using a form of question–answer conversation. The VH asked the participants 20 questions from the Myer-Briggs Type Indicator (MBTI) personality test. A short version of the MBTI was used for this experiment*. Each question is an A/B type choice. The participants had to choose either A or B and let the VH know what they chose verbally while marking their answers on a sheet of paper on the table. The verbal interaction would be simple and relatively constrained, so it is easy to control the VH's speech without harming the plausibility of the interaction. Participants' personality could be a factor to influence their perception of the VH. Kim et al. analyzed personality effects with a VH in AR and found an effect of introverted and extraverted participants.[13]

3.3.2 | Procedure

When participants arrived, the receptionist guided them to the questionnaire area. They were asked to read the informed consent and fill out a demographics questionnaire. Next, they were guided to the experimental room and instructed to sit on the chair in the corner of the room while starting the video and audio recording. The receptionist explained that they would be wearing a head-mounted display (HMD). They were informed that they would have an interaction with a VH, and she would ask 20 questions from the MBTI personality test, which were A/B type binary questions. Once the participant donned the HoloLens, a human controller (i.e., another experimenter) controlled the VH using a graphical user interface behind the scene. The receptionist and the VH behaved accordingly for each of the two study group descriptions during the interaction (see Section 3.1). Once the participant completed the interaction with the VH, the receptionist guided them out of the room and asked them to fill out a postquestionnaire.

After the postquestionnaire, the receptionist guided the participant back to the door of the experimental room and asked them to don the HoloLens once more while waiting in front of

*https://www.quia.com/sv/522966.html (2017-01-17)

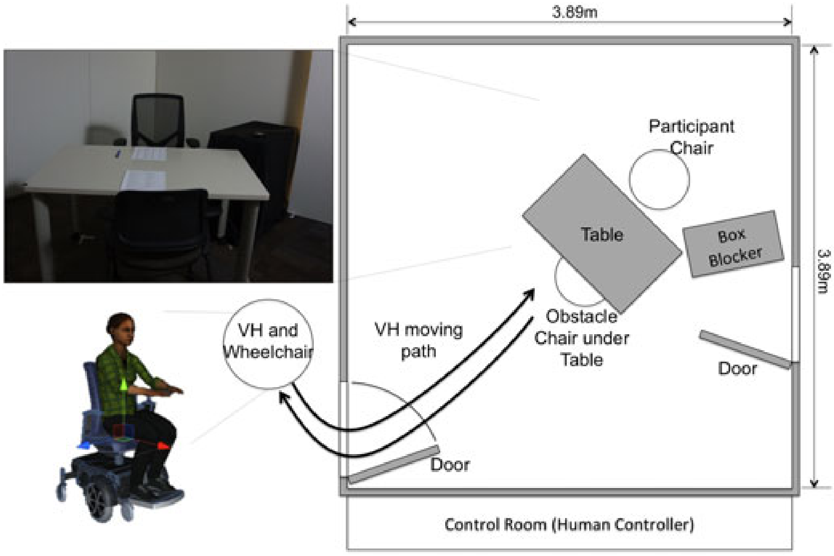

FIGURE 4 Experiment space. A table in the middle of the room, and the VH and the participant have a conversation across the table. A box blocker is placed next to the participant to investigate their walking path around the VH after the interaction

the door. Once the participant donned the HoloLens, the VH would be again visible at the table in the middle of the room (see Figure 4). The receptionist then instructed the participant to walk back to the chair where they had been sitting while answering the 20 questions, and we logged their walking trajectory using the OptiTrack system. Afterwards, the experimenters had a brief discussion with the participant about the perception and behavior of the VH.

3.4 | Participants

The subjective responsesand behavioral data of 22 participants were used for the analysis (11 for the PLS group and 11 participants for the IMP group; 14 males and eight females; age $M = 22.82$, $SD = 3.54$). All the participants received $15 USD for their participation. The total duration of the experiment per participant was approximately 1 hour.

3.5 | Dependent variables

Here, we describe multiple subjective questionnaires and behavioral measures that we included in the experiment.

3.5.1 | Perceptions

Social Presence: We used the social Presence (SP) questionnaire from Bailenson et al.[14] The questionnaire consists of five questions, covering the VH's authenticity and realism as well as the sense of "being together." We established the following hypothesis for SP based on the assumption that the plausible behaviors in this experiment might not only avoid the physical–virtual conflict but also strengthen the social connection due to the spatial and behavioral coherence:

- **SP-H**: The level of SP will be higher in the PLS group than in the IMP group.

Godspeed Questionnaire: We also adapted the "Godspeed" questionnaire from Bartneck et al.[15] This questionnaire was originally introduced to measure the user's perception of robots during human–robot interaction; however, we see similarities between robots and virtual humans and used it to assess the perception of the VH in the experiment. We used the four categories: anthropomorphism, animacy, likeability, and perceived intelligence. We expected that the responses for these categories would be generally more positive for the PLS group without any specific hypotheses.

3.5.2 | Avoidance behavior

The fact that participants walked around the VH could be an indication that they felt copresent with the VH in the shared AR space; thus, we were interested in whether the participants tried to avoid the VH and if so, whether there was any difference in their avoidance behavior among the study groups. We tracked the participant's walking path around the VH with two OptiTrack markers—one attached on the corner of the table and the other attached on the HoloLens—and we logged the HoloLens' head pose (see Figure 3). We expected the VH's plausible behavior that we adjusted would influence the participant's avoidance behavior as well. Thus, we hypothesized

- **AB-H**: The participants will more likely avoid the VH walking around it in the PLS group than in the IMP group.

4 | RESULTS

4.1 | Perceptions

We conducted two-tailed independent-samples *t* tests to compare the responses between the study groups ($\alpha = .05$), and confirmed the assumptions for the tests.

Social Presence: For Bailenson's SP, there was a statistically significant difference in the participants' SP responses for the IMP group ($M = 3.418$, $SE = 0.331$) and the PLS group ($M = 4.655$, $SE = 0.385$); $t(20) = -2.435$, $p = .024$ (Table 1, Figure 5). This suggests that the VH for the PLS group really does promote the participant's higher SP than the VH for the IMP group.

- **SP-H**: The result statistically support SP-H.

Godspeed Questionnaire: For the "Godspeed" responses, there was a statistically significant difference in the participant's perceived intelligence of the VH among the study groups ($M = 3.591$, $SE = 0.191$ for the IMP group and $M = 4.145$, $SE = 0.130$ for the PLS group; $t(20) = -2.402$, $p = .026$; Table 1, Figure 5). This suggests that the VH for the PLS group is perceived as more intelligent than the VH for the IMP group. Although there were no statistically significant differences for other variables, all had the trends of higher scores for the PLS group than for the IMP group as we expected.

- **Perceived intelligence**: A statistically significant difference was found (the PLS group > the IMP group).

TABLE 1 Independent-samples t-tests results for Bailenson SP and Godspeed measures

	t	*df*	*p*	Cohen's *d*
Social Presence				
SP (Bailenson)	-2.435	20	**0.024**	-1.038
Godspeed				
Anthropomorphism	-1.320	20	0.202	-0.563
Animacy	-1.753	20	0.095	-0.748
Likeability	-2.213	20	0.039*	-0.944
Perc. Intelligence	-2.402	20	**0.026**	-1.024

*Levene's test is significant ($p < .05$), suggesting a violation of the equal variance assumption.

4.2 | Avoidance Behavior

We observed that most of the participants avoided (walked around) the VH (see Figure 6). However, interestingly, three of the participants for the IMP group reported that they had walked through the VH. Although one of their walking trajectories was not directly passing through it, two trajectories completely ignored the VH and walked through it as shown in Figure 6—two red lines passing through the VH. The fact that we observed the cases ignoring the presence of the VH only for the IMP group was worth to think of the effect of our treatment in the user's avoidance behavior. This might suggest that the VH's spatial and behavioral coherence with the physical objects caused the VH to be perceived as more present in the physical space than if the VH behaved implausibly. Besides, the chi-squared tests showed a statistically significant difference when we used the count of the participants who reported that they ignored and passed through the VH (Table 2).

- **AB-H**: The observation of participants' walking path around the VH and the results from the chi-squared tests support the hypothesis.

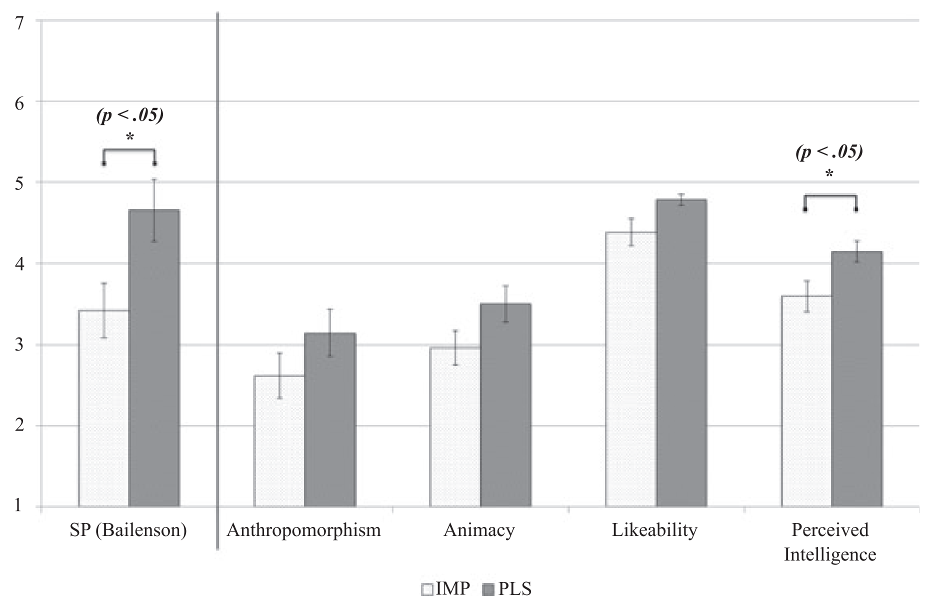

FIGURE 5 Mean comparison with standard errors for Bailenson SP (7-point Likert scale) and Godspeed measures (5-point semantic differential scale). IMP, implausible behavior; PLS, plausible behavior

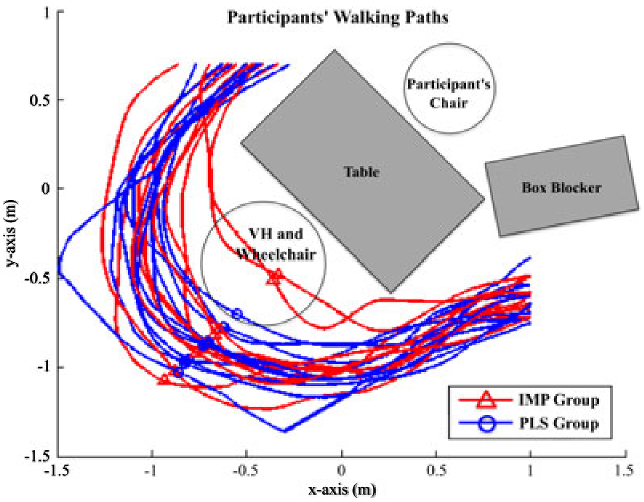

FIGURE 6 Participants' paths in the experimental room. Red lines for the implausible behavior (IMP) group and blue lines for the plausible behavior (PLS) group. Two red lines obviously ignore the VH and pass through it

TABLE 2 Chi-squared tests for avoidance behavior

Group		Reported path: Passed VH	Reported path: Avoided VH	Total
IMP	Count	3.00	8.00	11.00
	Exp. Count	1.50	9.50	11.00
PLS	Count	0.00	11.00	11.00
	Exp. Count	1.50	9.50	11.00
Total	Count	3.00	19.00	22.00
	Exp. Count	3.00	19.00	22.00
Chi-squared tests	**Value**	***df***	***p***	***Cramer's V***
Likelihood ratio	4.635	1	**0.031**	0.397
N	22			

Note. IMP = implausible behavior; PLS = plausible behavior; VH = virtual human.

5 | DISCUSSION

In the following, we discuss the results with the participants' informal postexperience comments and suggest some potential interpretations and implications. Finally, we discuss some unknown factors and potential limitations of the approach.

Social Presence and Perceived Intelligence: The results of Bailenson's SP show that the PLS group rates significantly higher than the IMP group, which supports our hypothesis SP-H. Interestingly, we found a positive effect for the PLS group in the estimated intelligence with statistical significance among the "Godspeed" measures. The VH's plausible behaviors seemed to be estimated as more intelligent like a real human. Based on the comment below, participants seemed to be positively affected when their lower expectation about the VH's awareness of the physical environment is contradicted by the VH's acknowledgement of the chair in the room.

> "I didn't know that she could tell the chair was there, … I think that's probably another reason why I decided to walk around her."

Avoidance Behavior: Based on comments and the observation that most participants looked at the VH while they were walking around it, we interpreted that visual perception played an important role in the avoidance behavior—which might indicate a low-level human instinct or reflex, but might also be the result of a cognitive process after factoring in the nature of the VH. Some comments indicate that they avoided the VH because they wanted to be respectful, which suggests that they treated the VH like a real human or a social being.

Potential Limitations and Unknown Factors: Given our experimental choice to have a VH ask the participant to move the chair, the approach might seem limited to situations where a VH is inherently present. However, the general notion that virtual contents should maintain plausible behaviors with respect to real objects can be extended to a broader concept of context-awareness of or response to the real scene by the virtual contents. If desired, the user will manipulate the physical environment as needed (e.g., open the door), which could further positively reinforce their sense of presence with the virtual object in a manner similar to the effect we saw in our experiment.

In our study design, we deliberately combined multiple typically occurring factors in AR related to the VH's plausible appearance and behaviors (natural occlusions, the observation of the experimenter's help to open the door, and the VH's request to move the chair). Our experiment elicited sufficiently strong effects that we believe it will be possible to design social presence experiments focusing on the contributions of individual factors in future work.

6 | CONCLUSION

A Virtual humans' ability to maintain the spatial and behavioral coherence with physical objects in AR could be an important feature that supports the illusion of presence in the real world and their (social) plausibility. Given the results from the study in this paper, we conclude that it is beneficial to have the VH's natural occlusions and proactive behavior asking help from the users to avoid implausible conflicts for higher social/copresence with the VH in AR. Moreover, the results suggest that the coherence influences the user's behaviors avoiding the VH's space while walking around it. These findings would help to design realistic VHs in AR and certain applications dealing with VHs that require strong physical–virtual realism and interactivity. In future work, we will investigate aspects that could influence human perception of virtual contents/humans in AR.

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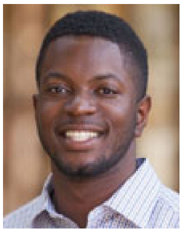
Kangsoo Kim is a PhD candidate in the Department of Computer Science at the University of Central Florida where he received his MS in 2015. He received his BS and MS degrees in Electronics and Computer Engineering in 2009 and 2011 from Hanyang University, Seoul, Korea. His research interests include virtual/augmented/mixed reality, virtual avatars/agents, and social interactions with emphasis on human perception, such as social/co-presence.



Divine Maloney is an undergraduate researcher in the Department of Computer Science at Sewanee: The University of the South where he studies Computer Science and Spanish. His research interest includes virtual and augmented reality, social interactions, and social justice.

Gerd Bruder is a research assistant professor at the Institute for Simulation and Training at the University of Central Florida. He received the PhD degree in Computer Science from the University of Münster in 2011. His research interests include virtual and augmented reality, surrogates and social interaction, perception and cognition, and 3D user interfaces.

Jeremy N. Bailenson is founding director of Stanford University's Virtual Human Interaction Lab, Thomas More Storke Professor in the Department of Communication, Professor (by courtesy) of Education, Professor (by courtesy) Program in Symbolic Systems, a Senior Fellow at the Woods Institute for the Environment, and a Faculty Leader at Stanford's Center for Longevity.

Gregory F. Welch is a computer scientist and engineer, with appointments Nursing, Computer Science (CS), and the Institute for Simulation and Training. Welch earned his BS in Electrical Engineering Technology from Purdue University (highest distinction), and his MS and PhD in CS from UNC Chapel Hill. Previously, he was a research professor at UNC and worked for NASA and Northrop. His research interests include virtual and augmented reality, and medical applications of computers.

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