International Conference on Artificial Reality and Telexistence
Eurographics Symposium on Virtual Environments (2018)
G. Bruder, S. Cobb, and S. Yoshimoto (Editors)

Blowing in the Wind: Increasing Copresence with a Virtual Human via Airflow Influence in Augmented Reality

Kangsoo Kim[†], Gerd Bruder[‡], and Gregory F. Welch[§]

The University of Central Florida, Orlando, FL, USA

Abstract

In a social context where two or more interlocutors interact with each other in the same space, one's sense of copresence with the others is an important factor for the quality of communication and engagement in the interaction. Although augmented reality (AR) technology enables the superposition of virtual humans (VHs) as interlocutors in the real world, the resulting sense of copresence is usually far lower than with a real human interlocutor.

In this paper, we describe a human-subject study in which we explored and investigated the effects that subtle multi-modal interaction between the virtual environment and the real world, where a VH and human participants were co-located, can have on copresence. We compared two levels of gradually increased multi-modal interaction: (i) virtual objects being affected by real airflow as commonly experienced with fans in summer, and (ii) a VH showing awareness of this airflow. We chose airflow as one example of an environmental factor that can noticeably affect both the real and virtual worlds, and also cause subtle responses in interlocutors. We hypothesized that our two levels of treatment would increase the sense of being together with the VH gradually, i.e., participants would report higher copresence with airflow influence than without it, and the copresence would be even higher when the VH shows awareness of the airflow. The statistical analysis with the participant-reported copresence scores showed that there was an improvement of the perceived copresence with the VH when both the physical–virtual interactivity via airflow and the VH's awareness behaviors were present together. As the considered environmental factors are directed at the VH, i.e., they are not part of the direct interaction with the real human, they can provide a reasonably generalizable approach to support copresence in AR beyond the particular use case in the present experiment.

CCS Concepts

• ***Human-centered computing*** → ***User studies; Mixed / augmented reality;*** • ***Computing methodologies*** → *Mixed / augmented reality;*

1. Introduction

Most research on natural social interaction between real and virtual humans (VHs) is related to the concepts of *social presence* or *copresence*—one's sense of "being (socially) connected" or "being together," respectively. To increase the sense of copresence with VHs, researchers have primarily focused on improving the visual/aural fidelity of the VH, e.g., its appearance [GSV*03] and verbal behaviors [MdKG09]. However, the surroundings in the space where the interlocutors, i.e., a VH and a real human, interact with each other could be also a critical factor influencing the sense of copresence. In this manner, Allwood considered that the environment is the fourth major parameter that characterizes a social activity (after purpose, roles and instrumentation) [All00].

The physical environment is particularly important in augmented reality (AR), where virtual content is visually merged with the real-world surroundings. In such environments, humans can expect natural and seamless interaction between the virtual content and the physical environment. For instance, Microsoft's HoloLens is addressing this challenge by employing a reconstructed virtual representation of the surrounding physical environment [Mic17]. On top of the spatial coherence between virtual content (including VHs) and the physical environment [KMB*17], our goal is to explore and understand how and in what ways the surrounding environment is contributing to human perception of natural interaction and whether we can leverage any such knowledge to increase the sense of copresence with VHs.

Related work by Lee et al. [LKD*16] suggests that subtle movements of a computer-mediated physical object between real humans

† E-mail: kskim@knights.ucf.edu (corresponding author)
‡ E-mail: bruder@ucf.edu
§ E-mail: welch@ucf.edu

and a VH can improve their sense of copresence. In their experiment, they used a wobbly table spanning from the real to the virtual world so that participants could see and feel movements of the table caused by the VH and also cause it to move. Although this is a prime example of physical–virtual influence, in order to generalize this approach it would be important to understand if similar effects can be induced via subtler environmental events, for example, where real human subjects do not actively participate in the stimuli events but merely observe the events. Also, despite the positive results, there was still some ambiguity as to which aspect of the wobbly table setup was causing the increase in copresence; it could be the tight physical–virtual connectivity via visual-motor synchrony, but it could also be the VH's reactive behaviors exhibiting awareness of the wobbling. Thus, we want to further investigate the effects of subtle environmental physical–virtual interactivity in real–virtual human interactions with the following possible influences on copresence:

- the virtual world is affected by events in the real world related to airflow caused by a physical fan, and
- the virtual human is showing non-verbal awareness of the real-world airflow.

Previously, we had an exploratory study adapting the airflow influence and VH's awareness behavior in a physical setting where the VH was displayed on a projection screen [KSW16]. Although statistically significant differences were not found, several possible reasons for the negative effects were discussed, such as less attention towards the environment compared to the interaction scenario (practice job interview) and the clear distinction between the virtual and real worlds in the experimental setting at the time. Here, we present a human-subject study in which we situated a real–virtual human interaction in an AR environment with a HoloLens head-mounted display (HMD), where the virtual and physical worlds are visually connected more seamlessly, while considering the lessons learned from the previous study. We analyze the effects of increasing the physical–virtual connectivity via subtle airflow and isolate the perceptual effects of the physical–virtual connectivity from those of the VH's environmentally aware behavior.

This paper is structured as follows: Section 2 provides background information on copresence, physical–virtual connectivity, and environmental awareness of VHs. Section 3 describes our experiment. Section 4 presents the results, which are discussed in Section 5. Section 6 concludes the paper and presents future work.

2. Background

This section provides background information on definitions of copresence, social presence, and presence, the sense of airflow in virtual environments, and environmentally aware behavior of VHs.

2.1. Copresence, Social Presence, and Presence

There is an ongoing debate in the research community about precise definitions for *social presence* and *copresence*, as distinct from the concept of *presence*. While presence usually refers to one's sense of "being there" in a virtual environment, the concepts of copresence and social presence might be described as how one perceives another human's presence in a sense of "being together," and how much they feel "socially connected," respectively. Zhao pointed out the confusion of those concepts and tried to differentiate them [Zha03]. He considered human copresence in two aspects: "the physical conditions in which human individuals interact and the perceptions and feelings they have of one another." Each of these aspects might be complementary to each other to determine one's perceived sense of copresence with a VH during an interaction.

Slater addressed an important concept for presence, called *plausibility illusion (Psi)*. Psi "refers to the illusion that the scenario being depicted is *actually occurring*," which "requires a credible scenario and plausible interactions between the participant and objects and virtual characters *in the environment*" (emphases added) [Sla09]. Due to the nature of Psi as it relates to interactions between real and virtual objects and humans, it could be highly related to the concepts of social presence and copresence as well. Harms and Biocca considered copresence as one of several sub-dimensions that embody social presence [HB04], and Blascovich et al. defined social presence both as a "psychological state in which the individual perceives himself or herself as existing within an *interpersonal environment*" (emphasis added) and "the degree to which one believes that he or she is in the presence of, and dynamically interacting with, other veritable human beings." [Bla02, BLB*02].

Considering the definitions addressed above, we expect that the plausibility of the context and the surrounding environment where the social interaction takes place could be important factors in the sense of social presence or copresence, for example, due to enhanced mutual awareness [Gof63] or a shared inter-personal environment [Bla02, BLB*02].

2.2. Physical–Virtual Influences via Airflow

Previously, airflow has been introduced as a tactile modality that can increase the sense of presence in a virtual environment by associating one's physical feeling of wind in the real space with the context in the virtual environment.

For example, Dinh et al. evaluated multimodal (including wind) effects on presence and memory while navigating a virtual environment, and found significant improvements on both variables [DWS*99]. Moon et al. developed the "WindCube", which consists of multiple small fans in a frame, which allowed users to feel the wind while experiencing a virtual environment [MK04]. Similarly, Hülsmann et al. implemented a multimodal CAVE system employing the sense of wind and warmth, and suggested a positive influence on the sense of presence [HFMW14]. Also, Feng et al. used wind along with vibration cues in a virtual navigating scenario using a HMD [FDL16]. Lehmann et al. also conducted a user study about the sense of presence while experiencing a ski simulation with wind sensations [LGWS09], and they reported a higher sense of presence with the wind. Deligiannidis et al. investigated the relationship between the wind sensation and user's task performance using a scooter riding simulation, "VR Scooter," in virtual reality (VR) [DJ06]. They found that participants completed the riding task faster and reported more positive user experience when they experienced the virtual scooter simulation with wind sensations.

Although there are some previous works supporting the positive effects of airflow on the perceived presence and task performance in VR, there is still lack of research about the effects of airflow in the sense of copresence with VHs, particularly in AR. We believe it could be beneficial to increase the sense of copresence with VHs by achieving a tight physical–virtual connection via airflow influencing both virtual and real objects in an AR environment, and we investigate how subtle and indirect experience of the airflow can affect the sense of copresence with VHs. For example, users might report a higher sense of copresence with a VH when they observe real wind blowing virtual objects in a shared AR environment, which could be visually plausible and induce the impression that the VH might have the same perception of wind as the real human.

2.3. Virtual Humans and Environmentally Aware Behavior

Virtual humans are used in many social interaction scenarios, such as educational, medical, and interview training. For instance, Dieker et al. made use of several virtual characters to train students who planned to be a teacher [DRL*13]. Chuah et al. developed interactive virtual humans with a physical lower body for medical training and concluded that increasing the physicality of virtual humans could increase social presence [CRW*13]. Rizzo et al. evaluated a fully autonomous VH platform called "SimSensei" that could recognize a user's verbal and nonverbal behaviors for identifying mental illnesses, and showed its potential in different medical and military applications [RSD*14]. Huang et al. developed the "Rapport Agent," which could interact with users autonomously, for an interview scenario, and measured the level of social presence with the VH as a rapport measure [HMG11]. Hoque et al. used an interactive and expressive VH and showed its effectiveness in practicing job interviews [HCM*13]. Although previous research has shown promising results, the level of copresence with VHs is still very different from that between real humans.

To make up the gap, researchers and practitioners primarily focused on improving the visual and aural fidelity of VHs. However, a VH's nonverbal behaviors expressing awareness of objects or events in the *physical* space could be useful to enhance the physical–virtual connection and be perceived as a plausible reaction in AR environments. For example, Andrist et al. presented bidirectional gaze that a VH coordinates with the gaze of a user towards physical objects on a table, while interacting with the VH [AGM17], and found that the gaze behavior supported more effective communication. Similarly, Kim et al. evaluated a VH's joint attention and gaze behavior with participants' expectations and found increased social presence [KNBW15]. Kim et al. found that a VH exhibiting awareness of the surrounding environment and influencing physical objects, e.g., turning on a lamp, could improve the trustworthiness of the VH and the user's perceived social presence with it [KBH*18].

This environmentally aware behavior in physical environments tends to be overlooked in VHs in augmented and virtual reality due to the nature of virtuality (i.e., lack of physicality); however, VHs that exhibit awareness of the physical surrounding objects and events in AR might be perceived as more compelling and increase the sense of copresence.

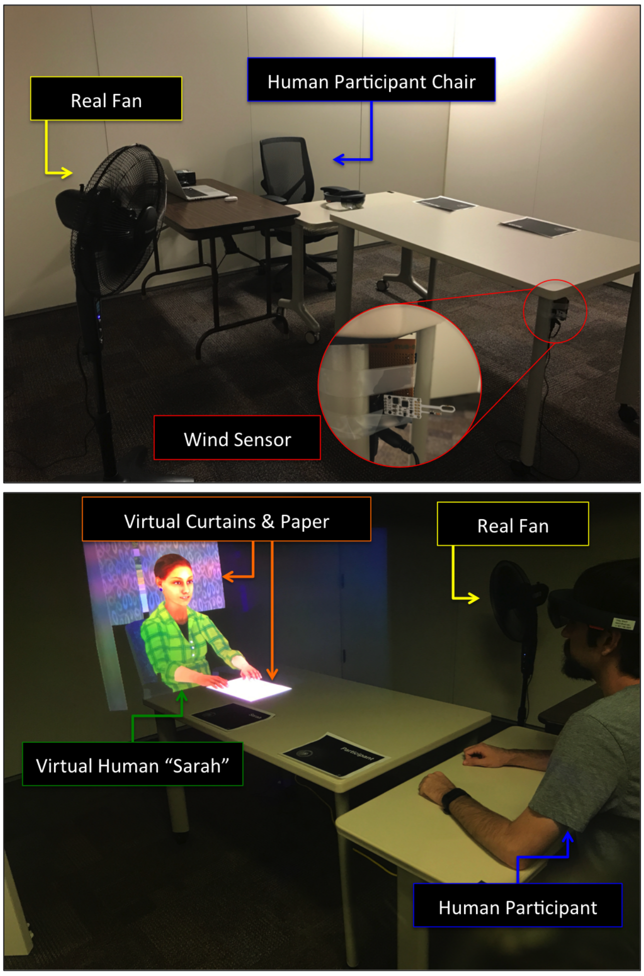

Figure 1: Experimental setup captured from two different camera angles. Participants were seated opposite from a virtual human on a physical table. A physical fan was placed on the side between the participant and virtual human, and a wind sensor was used to detect airflow that induced a state of fluttering in the virtual paper.

3. Experiment

In this section we present the experiment which we conducted to investigate the effects of subtle physical–virtual influences and a VH's environmentally aware behavior on copresence.

3.1. Material

We implemented a female VH called "Sarah" for this experiment. The VH could speak with the participants and perform upper torso gestures (e.g., hand, arm, and head gestures). The VH was displayed via a Microsoft HoloLens HMD, which participants wore during the interaction with the VH. Participants and the VH were co-located in an office-like AR space as shown in Figure 1, giving the participants the impression of being seated at a table across from the VH. The physical table occluded the VH's lower body to maintain the visual plausibility. A physical rotating fan was placed next to the table in the middle of the two interlocutors, and oriented such that the airflow would occasionally blow in the direction of the virtual paper and curtains as the fan oscillated. A wind sensor (Modern Device Wind Sensor Rev. P[†]), hidden below the table (red circles in Figure 1), would detect the airflow from the fan, allowing the virtual paper and curtains to flutter according to the real wind for the experimental conditions. The sensor has a wide measure range of wind speed (0–150 MPH), which we used to trigger the virtual contents' fluttering animations, and there was no noticeable delay between the wind sensing and the animation triggering. Hence, this approach could provide a higher fidelity and realism than with cruder setups, e.g., based on tracking the fan's pose alone. Cloth physics simulation in Unity3D was used to render the fluttering animations as natural as possible. The experimenter acted as a remote operator of the VH in a human-in-the-loop (i.e., Wizard-of-Oz) based experimental setup and triggered pre-defined verbal and nonverbal behaviors for the VH using a graphical user interface (GUI). The VH maintained a slightly pleasant facial expression throughout the interaction.

3.2. Methods

To investigate the effects of the physical–virtual interactivity via airflow and the VH's awareness behavior, we wanted to give the participants a chance to directly compare how they felt about the VH in different experimental conditions. A within-subject design is the most effective approach to control for individual experience/gender/personality factors with respect to the interaction with the VH. Thus, we used a within-subjects design with three conditions, which participants experienced in a counter-balanced order:

- ***Control*** condition,
- *Physical–Virtual Influence (**PVI**)* condition, and
- *Environment-Aware Behavior (**EAB**)* condition.

In all conditions, the experiment consisted of a conversational interaction that participants had with the VH, which was based on simple and casual questions about personal preferences and experience in an AR environment. For example, the VH asked participants personal questions such as, "When is your birthday?" [‡] Thirty questions were prepared and divided into three sets (ten questions per set), and each set was used for three conditions in the experiment. The question sets consisted of similar patterns of questions and the order of the sets were also considered to avoid the undesired effects by the question sets. The interaction between the participants and the VH was straightforward and did not have conversational dynamics. The experimenter simply triggered the VH's verbal and nonverbal behaviors via GUI buttons throughout the interaction with the participants, so the experimenter's influence should be minimized.

In the **PVI** condition, a virtual paper on the table in front of the VH and virtual curtains behind it appeared to flutter as a result of the physical fan that was located on the side between the VH and participant. Participants could also see the real papers, which fluttered on the table, and compare the real and the virtual papers together (see Figure 1). The physical fan blowing the virtual objects was chosen as a subtle environmental event to strengthen the connection between physical and virtual spaces, and potentially influence the sense of copresence. We pursued to emphasize the inter-space connection by a different sensing modality other than the traditional visual and aural senses, which might exceed one's expectation for virtual content in a real environment. We were curious whether observing the fluttering virtual objects would have an impact on copresence, even when the participant was not directly involved in the fan-blowing event—unlike the wobbly table case in [LKD*16].

In the **EAB** condition, the VH would additionally occasionally exhibit attention toward the fan by looking at it or putting its hand on the virtual paper to stop the fluttering. The VH did not make any verbal acknowledgement about the fan wind. We chose the VH's gaze toward the fan because gaze has been considered as an informative cue to convey the direction of interest [FBT07], so we wanted to express the VH's awareness of the fan and wind with its gaze in a subtle way together with the paper holding gesture.

In the **Control** condition, the virtual paper did not flutter and the VH never demonstrated any awareness of the physical fan although the fan was on and the real papers on the table were fluttering by the real wind. A brief description of the three conditions is shown in Figure 2.

3.3. Participants

We recruited 18 participants (8 females and 10 males; age $M = 21.44$, $SD = 4.49$, range: 18–37) from our university community for the study. Seven of them had prior experience with VR/AR headsets, but the number of experiences was less than five times. The rest of them did not have any VR/AR headset experiences. All participants received a monetary compensation for their participation after the experiment (duration: 40–50min).

3.4. Procedure

Once participants arrived, they received an informed consent document and filled out a demographics questionnaire. We measured their interpupillary distance (IPD), which was applied for the HoloLens setting. In the within-subjects design, participants experienced the three experimental conditions in a counter-balanced order. We explained to participants that they would be interacting with a VH three times, and be asked to complete a post-questionnaire after each interaction to assess their sense of copresence with the VH. Participants initially saw virtual blinds placed between themselves and the VH at each time when the participants wore the HoloLens and they could see and start interacting the VH after the blinds moved up. In this way, we wanted to prevent the participants from feeling that the VH suddenly appeared when they donned the headset, which might influence their sense of copresence with the VH. During the interaction, the VH verbally asked

[†] https://moderndevice.com/product/wind-sensor-rev-p (Accessed 2018-10-04)

[‡] For the conversational interaction with the VH, thirty questions were extracted from http://allysrandomage.blogspot.com/2007/06/101-random-questions.html (Accessed 2018-10-04).

Condition	Physical Fan	Virtual Curtain & Paper Fluttering	Virtual Human's Awareness Behavior (Holding the Paper & Looking at the Fan)
(A) Control	ON	NO	NO
(B) PVI	ON	YES	NO
(C) EAB	ON	YES	YES

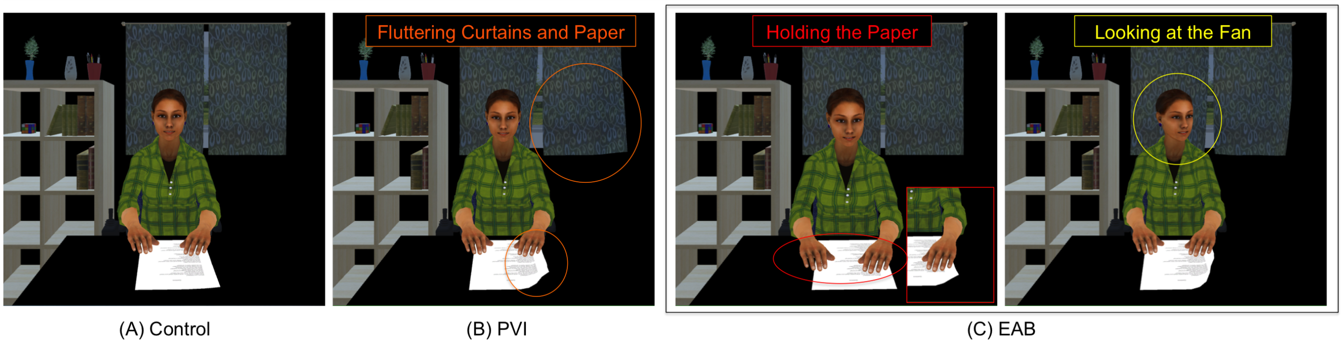

Figure 2: Experimental conditions. (A) Control, (B) PVI (orange circles: fluttering virtual paper and curtains), and (C) EAB (red circle: holding the paper gesture, red rectangle: less fluttering after holding, yellow circle: looking at the fan).

participants ten casual questions on personal experience or preference as described above (see Section 3.2), and they verbally responded yes/no or brief answers to the questions. After experiencing each experimental condition, they were guided to complete a questionnaire measuring the level of perceived copresence with the VH. After all of the three conditions were completed, participants filled out a final post-questionnaire that evaluated the participant's preference among the three interactions with the VH and in which condition they felt the VH the most interactive, and had a brief interview with the experimenter to confirm their perception of the manipulations and collect their overall comments about the interactions with the VH. Finally, they received a monetary compensation for their participation and then departed.

3.5. Copresence Measure

Different subjective questionnaires have been introduced to measure copresence (or social presence) with VHs (e.g., [BBBL03, BHSS00]). These questionnaires usually cover and combine multiple aspects together, such as a sense of copresence (i.e., being together in the same place), a degree of social connection (i.e., how closely they communicate/interact with each other), and a sense of realism (i.e., the VH's human-likeness). While such a combined questionnaire is beneficial when the goal is to measure the overall human perception of the VH, we wanted to evaluate specifically the sense of copresence, which might be affected by our experimental manipulations, i.e., the physical–virtual influence by airflow and the VH's environmentally aware behavior. Thus, we prepared six questions relevant to the sense of "being (physically) together", extracting some of questions from existing questionnaires. CP 1–3 (see Table 1) were extracted from Bailenson et al. [BBBL03] and CP 4 was from Basdogan et al. [BHSS00]. We added three of our own questions, CP 5, CP 6-1, and CP 6-2. The absolute difference of CP 6-1 and CP 6-2 was calculated and used as a single value, which indicates that the participant and the VH are in the same place. In other words, the smaller absolute difference of CP 6-1 and CP 6-2 means that the participant felt more that he/she and the VH were in the same place somewhere in between the virtual space and the physical space. All questions used 7-point Likert scales, and we computed the averaged score as a representative score of copresence.

Among the three experimental conditions, we hypothesized that

- **H1**: the reported sense of copresence with the VH for the PVI condition would be higher than for the Control condition, and
- **H2**: the reported sense of copresence with the VH for the EAB would be even higher than for the PVI.

Table 1: Copresence questionnaire used in the experiment.

CP: Co-Presence (Sense of Being Together in the Same Place)
CP 1. I perceived that I was in the presence of the person in the room with me. (1: Strongly Disagree, 7: Strongly Agree) CP 2. I felt the person was watching me and was aware of my presence. (1: Strongly Disagree, 7: Strongly Agree) CP 3. I would feel startled if the person came closer to me. (1: Strongly Disagree, 7: Strongly Agree) CP 4. To what extent did you have a sense of being with the person? (1: Not at all, 7: Very much) CP 5. To what extent was this like you were in the same room with the person? (1: Not at all, 7: Very much) ∗CP 6-1. I felt I was in the ____ space. (1: Virtual, 7: Physical) ∗CP 6-2. I felt the person was in the ____ space. (1: Virtual, 7: Physical)
∗The absolute difference between CP 6-1 and CP 6-2 was used as a single value.

Table 2: Friedman test results for copresence.

Friedman test				
Condition	Mean Rank	Median	N	18
Control	1.53	3.25	Chi-Square	7.300
PVI	2.19	3.67	df	2
EAB	2.28	3.67	Asymp. Sig.	**.026**

Table 3: Results from Wilcoxon signed-rank tests for copresence.

Wilcoxon signed-rank tests			
	PVI-Control	EAB-PVI	EAB-Control
Z	-1.309[a]	-.094[b]	-1.988[a]
Asymp. Sig.	.191	.925	**.047**

a. Based on negative ranks, b. Based on positive ranks.

4. Results

For the analysis, we computed the averaged scores from the six questionnaire responses (see Table 1). The internal consistency of the six responses was high as shown by Cronbach's alpha ($\alpha = .716$). Considering sample size, dependency, and ordinal characteristics of the questionnaire responses, a non-parametric Friedman test was used for the analysis of the participants' responses on the copresence questions with a significance level at $\alpha = .05$. We found a significant main effect of the experimental conditions on the participants' estimated copresence, $\chi^2(2) = 7.300, p = .026$ (Table 2).

Median (IQR) copresence levels for the Control, the PVI, and the EAB running trials were 3.25 (2.42 to 4.04), 3.67 (2.79 to 4.38), and 3.67 (2.67 to 4.29), respectively (see Figure 3). For the post-hoc analysis, Wilcoxon signed-rank tests were conducted. We found a significant difference between the Control and the EAB conditions ($Z = -1.988, p = .047$), while no significant differences were found between the Control and the PVI conditions ($Z = -1.309$, $p = .191$), and between the PVI and the EAB conditions ($Z = -0.094$, $p = .925$) (see Table 3).

This indicates that the sense of copresence was higher when the VH's environment-aware behavior is present along with the physical–virtual airflow interactivity, compared to when those manipulations were absent. The magnitudes suggest a higher copresence for the PVI and the EAB conditions than the Control condition. Our original hypotheses H1 and H2 was not fully supported by the results, i.e., we did not see significant differences among all the conditions. However, our results partially support H2 by that participants felt higher sense of copresence when the VH exhibited awareness behaviors accompanied by the physical airflow affecting virtual objects.

After the participants experienced all three conditions, we asked them in which VH condition they felt the most interactivity with the surrounding environment and their preference among the conditions. The results show that the participants perceived the VH in the EAB condition as the most interactive with respect to the real environment, and the PVI condition was preferred the most (see Figure 4). The Control condition was evaluated as the least interactive and the least preferred while there were a few participants who did not perceive a difference among the conditions.

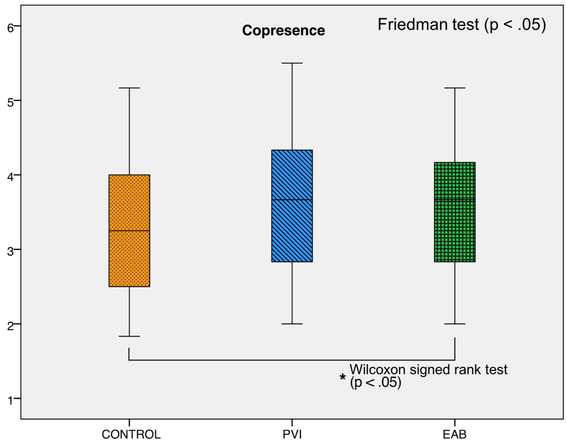

Figure 3: Copresence scores for the three experimental conditions. The PVI's median value was the highest followed by EAB and the Control condition.

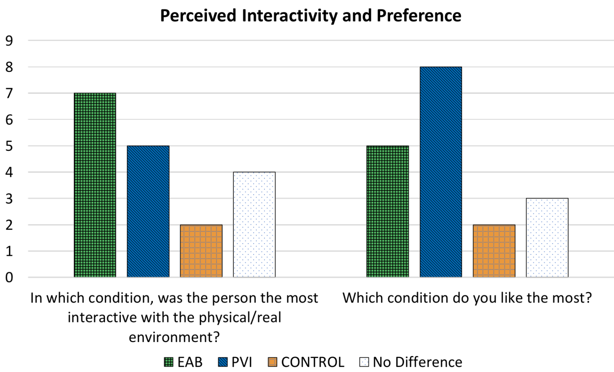

Figure 4: Perceived interactivity and preference. Y-axis is the number of participants who chose the condition for the questions.

5. Discussion

Based on our results, we found a significant main effect on copresence by introducing airflow and VH's awareness behavior in a shared AR environment. Our finding suggests that peripheral environmental events, such as fan-blowing objects and observing them, impact one's sense of copresence with the VH that they interact with, and this could provide a useful reference for practitioners who want to increase the copresence level by physical–virtual environmental influences.

Our results suggest a higher copresence for the PVI and the EAB compared to the Control condition, particularly between the Control and the EAB conditions with statistical significance, which is also supported by our participants' informal comments after the experiment. Most participants indicated that they noticed the influence of physical airflow on the virtual paper and curtains, and the VH's awareness behaviors. Here are a few of the participants' comments that we collected in this experiment:

> **Comment 1**: "It (airflow) made the environment feel more real. It definitely helped."
>
> **Comment 2**: "It (airflow) made me feel like I was really in the same room (with the VH)."
>
> **Comment 3**: "Oh, that's cool. It's almost like they were blending the physical world and the virtual world. ... I could see that (real) paper fluttering when her (virtual) paper fluttered on the desk. It seemed like a continuum."

The post-hoc pair-wise analysis showed that the sense of copresence was significantly higher in the EAB condition compared to the Control condition. This indicates that the VH's awareness behaviors played a role in improving the sense of copresence on top of the physical–virtual airflow simulation.

It is further interesting to see that the participants seemed to have preferred the PVI condition over the EAB condition. This trend might be explained by the point that in the EAB condition the VH looked at the fan during the conversation, which could cause participants to feel as if their conversation partner is distracted by the environmental event and not paying a full attention to them. While the EAB condition helped to bridge the gap between the real and virtual spaces, it also made the VH's behavior more subject to interpretations of natural behavior in the real world.

As expected, observing the subtle airflow caused by a physical fan without active participation/involvement was not quite as effective as the wobbly table experience in [LKD*16], which directly involved participants in the interaction. Compared to the direct involvement of the human participants in the wobbly table movement, the fluttering virtual paper and airflow were not designed to be an integral part of the interaction between the participants and the VH in our experiment. This might also have made the VH's reactive nonverbal behaviors to the fan/paper less essential for the interaction and less influential to the participants. However, while it would be possible to create a similar level of involvement, e.g., by letting participants position the fan or using hand-held fans, it is encouraging to see that even our subtle indirect factors in this experiment had a significant effect on copresence.

Also, our results suggest that the influence by the subtle indirect physical–virtual interactivity could be observed and compared more clearly when the physical–virtual events appear to be implausible and incoherent with the surrounding environment. In this sense, the statistically significant main effect in the present study could be explained by the use of an AR HMD, which can increase the user's expectations related to the physical–virtual interactivity, contrary to a projection screen displaying the VH in our previous study [KSW16]. Regarding the coherency, we intentionally placed real paper on the table so that participants could compare the fluttering movement among the real paper and the virtual paper. Without the real paper, it is unlikely that we would have been able to show strong effects related to the virtual paper's behavior because paper can be static for other reasons, e.g., insufficient wind.

One general factor that might have limited the effect of the airflow and the VH's reactive awareness behavior on the perceived sense of copresence with the VH in this experiment could be related to the narrow field of view (FOV) of the HoloLens. Due to the narrow FOV, participants were not continuously able to see both the VH and the paper/fan while they were looking at objects in the environment. Also, the VH's body could be cropped by the narrow FOV such that participants could see only a portion of the upper body of the VH, impacting the overall copresence level [LBHW18].

Our results are interesting in that we investigated the effects of a less researched modality, i.e., wind, which enables a subtle stimulus on the sense of copresence. We chose the wind modality because it has not been researched in depth in AR environments so far despite the fact that events caused by wind are common occurrences in our real life and potentially powerful in influencing one's perception of AR content. Our approach to reinforce the connectivity between the real and virtual worlds by using wind is not limited to copresence research with VHs, but could be employed in various AR applications.

6. Conclusion

System evaluation with perception studies involving human subjects has become a more common practice in the field of AR and intelligent virtual agents [KBB*18, NKH*18]. In this paper, we described a human-subject study in which we analyzed the effects that physical–virtual connectivity and awareness behaviors can have on the sense of copresence with a virtual human in AR. We demonstrated that a virtual human's awareness behavior along with subtle environmental events related to airflow caused by a physical fan can lead to higher subjective estimates of copresence with the virtual human. Our results show that the airflow and responsive behavior play an important role in increasing the perceived copresence with virtual humans. Our experiment investigated the effects of subtle environmental events and virtual human behaviors on the sense of copresence, which extends related research involving physical–virtual environmental influences (in particular, the wobbly table [LKD*16]). Our results help to clarify the findings in this related work, in which the source of the observed increase in copresence could not be clearly identified.

In future work, we plan to investigate other modalities to increase the dynamics and fidelity of interaction between the real and virtual spaces in AR, and apply them to a social context with VHs, which can benefit from a high level of copresence.

Acknowledgements

This material includes work supported in part by the National Science Foundation (NSF) under Grant Number 1800961 (Dr. Tonya Smith-Jackson, IIS) and 1564065 (Dr. Ephraim P. Glinert), as well as the Office of Naval Research (ONR) under Grant Number N00014-17-1-2927 (Dr. Peter Squire, Code 30). We also acknowledge Florida Hospital for their support of Prof. Welch via their Endowed Chair in Healthcare Simulation.

References

[AGM17] Andrist S., Gleicher M., Mutlu B.: Looking Coordinated: Bidirectional Gaze Mechanisms for Collaborative Interaction with Virtual Characters. In *Proceedings of CHI* (2017). 3

[All00] Allwood J.: An activity based approach to pragmatics. In *Abduction, Belief and Context in Dialogue: Studies in Computational Pragmatics*, Bunt H., Black W., (Eds.). John Benjamins Publishing Company, 2000, pp. 47–80. 1

[BBBL03] Bailenson J. N., Blascovich J., Beall A. C., Loomis J. M.: Interpersonal distance in immersive virtual environments. *Personality and Social Psychology Bulletin 29*, 7 (2003), 819–833. 5

[BHSS00] Basdogan C., Ho C.-H., Srinivasan M. A., Slater M.: An experimental study on the role of touch in shared virtual environments. *ACM Transactions on Computer-Human Interaction 7*, 4 (2000), 443–460. 5

[Bla02] Blascovich J.: Social Influence within Immersive Virtual Environments. In *The Social Life of Avatars*, Schroeder R., (Ed.), Computer Supported Cooperative Work. Springer London, 2002, pp. 127–145. 2

[BLB*02] Blascovich J., Loomis J., Beall A. C., Swinth K. R., Hoyt C. L., Bailenson J. N.: Immersive virtual environment technology as a methodological tool for social psychology. *Psychological Inquiry 13*, 2 (apr 2002), 103–124. 2

[CRW*13] Chuah J. H., Robb A., White C., Wendling A., Lampotang S., Kopper R., Lok B.: Exploring Agent Physicality and Social Presence for Medical Team Training. *Presence: Teleoperators and Virtual Environments 22*, 2 (2013), 141–170. 3

[DJ06] Deligiannidis L., Jacob R. J.: The VR scooter: Wind and tactile feedback improve user performance. In *Proceedings of IEEE Symposium on 3D User Interfaces* (2006), pp. 143–150. 2

[DRL*13] Dieker L. A., Rodriguez J. A., Lignugaris/Kraft B., Hynes M. C., Hughes C. E.: The Potential of Simulated Environments in Teacher Education: Current and Future Possibilities. *Teacher Education and Special Education: The Journal of the Teacher Education Division of the Council for Exceptional Children 37*, 1 (2013), 21–33. 3

[DWS*99] Dinh H. Q., Walker N., Song C., Kobayashi A., Hodges L. F.: Evaluating the Importance of Multi-Sensory Input on Memory and the Sense of Presence in Virtual Environments. In *IEEE Virtual Reality (VR)* (1999), IEEE Comput. Soc, pp. 222–228. 2

[FBT07] Frischen A., Bayliss A. P., Tipper S. P.: Gaze Cueing of Attention. *Differences 133*, 4 (2007), 694–724. 4

[FDL16] Feng M., Dey A., Lindeman R. W.: The Effect of Multi-Sensory Cues on Performance and Experience During Walking in Immersive Virtual Environments. In *Proceedings of IEEE Virtual Reality* (2016), pp. 173–174. 2

[Gof63] Goffman E.: *Behavior in Public Places: Notes on the Social Organization of Gatherings*. The Free Press, New York, 1963. 2

[GSV*03] Garau M., Slater M., Vinayagamoorthy V., Brogni A., Steed A., Sasse M. A.: The Impact of Avatar Realism and Eye Gaze Control on Perceived Quality of Communication in a Shared Immersive Virtual Environment. In *SIGCHI Conference on Human Factors in Computing Systems* (New York, New York, USA, 2003), ACM Press, pp. 529–536. 1

[HB04] Harms C., Biocca F.: Internal consistency and reliability of the networked minds measure of social presence. In *Seventh Annual International Presence Workshop: Presence 2004* (2004), pp. 246–251. 2

[HCM*13] Hoque M., Courgeon M., Martin J.-C., Mutlu B., Picard R. W.: Mach: My automated conversation coach. In *Proceedings of ACM International Joint Conference on Pervasive and Ubiquitous Computing* (2013), pp. 697–706. 3

[HFMW14] Hülsmann F., Fröhlich J., Mattar N., Wachsmuth I.: Wind and Warmth in Virtual Reality: Implementation and Evaluation. In *Proceedings of the 2014 Virtual Reality International Conference* (2014), pp. 28:1–8. 2

[HMG11] Huang L., Morency L.-P., Gratch J.: Virtual Rapport 2.0. In *Intelligent Virtual Agents (Lecture Notes in Artificial Intelligence)* (2011), Vilhjálmsson H., Kopp S., Marsella S., Thórisson K., (Eds.), vol. 6895 of *Lecture Notes in Computer Science*, Springer Berlin Heidelberg, pp. 68–79. 3

[KBB*18] Kim K., Billinghurst M., Bruder G., Been-Lirn Duh H., Welch G. F.: Revisiting Trends in Augmented Reality Research: A Review of the 2nd Decade of ISMAR (2008–2017). *IEEE Transactions on Visualization and Computer Graphics (TVCG) Special Issue on IEEE International Symposium on Mixed and Augmented Reality (ISMAR)* (2018). 7

[KBH*18] Kim K., Boelling L., Haesler S., Bailenson J. N., Bruder G., Welch G. F.: Does a Digital Assistant Need a Body? The Influence of Visual Embodiment and Social Behavior on the Perception of Intelligent Virtual Agents in AR. In *Proceedings of IEEE International Symposium on Mixed and Augmented Reality (ISMAR)* (2018). 3

[KMB*17] Kim K., Maloney D., Bruder G., Bailenson J. N., Welch G. F.: The effects of virtual human's spatial and behavioral coherence with physical objects on social presence in AR. *Computer Animation and Virtual Worlds 28*, 3-4 (2017), e1771. 1

[KNBW15] Kim K., Nagendran A., Bailenson J., Welch G.: Expectancy Violations Related to a Virtual Human's Joint Gaze Behavior in Real-Virtual Human Interactions. In *Proceedings of the International Conference on Computer Animation and Social Agents* (2015), pp. 5–8. 3

[KSW16] Kim K., Schubert R., Welch G.: Exploring the Impact of Environmental Effects on Social Presence with a Virtual Human. *Lecture Notes in Artificial Intelligence (IVA 2016) 10011* (2016), 470–474. 2, 7

[LBHW18] Lee M., Bruder G., Höllerer T., Welch G.: Effects of unaugmented periphery and vibrotactile feedback on proxemics with virtual humans in ar. *IEEE Transactions on Visualization and Computer Graphics 24*, 4 (2018), 1525–1534. 7

[LGWS09] Lehmann A., Geiger C., Wöldecke B., Stöcklein J.: Poster: Design and Evaluation of 3D Content with Wind Output. In *Proceedings of IEEE Symposium on 3D User Interfaces* (2009), pp. 151–152. 2

[LKD*16] Lee M., Kim K., Daher S., Raij A., Schubert R., Bailenson J., Welch G.: The Wobbly Table: Increased Social Presence via Subtle Incidental Movement of a Real-Virtual Table. In *Proceedings of the IEEE Virtual Reality* (2016), pp. 11–17. 1, 4, 7

[MdKG09] Morency L. P., de Kok I., Gratch J.: A probabilistic multimodal approach for predicting listener backchannels. *Autonomous Agents and Multi-Agent Systems 20*, 1 (2009), 70–84. 1

[Mic17] Microsoft: Spatial mapping (windows mixed reality). https://developer.microsoft.com/en-us/windows/mixed-reality/spatial_mapping, April 22 2017. 1

[MK04] Moon T., Kim G. J.: Design and Evaluation of a Wind Display for Virtual Reality. In *Proceedings of the ACM symposium on Virtual reality software and technology* (2004), pp. 122–128. 2

[NKH*18] Norouzi N., Kim K., Hochreiter J., Lee M., Daher S., Bruder G., Welch G.: A Systematic Survey of 15 Years of User Studies Published in the Intelligent Virtual Agents Conference. In *ACM International Conference on Intelligent Virtual Agents* (2018). 7

[RSD*14] Rizzo A., Scherer S., DeVault D., Gratch J., Artstein R., Hartholt A., Lucas G., Marsella S., Morbini F., Nazarian A., Stratou G., Traum D., Wood R., Boberg J., Morency L.-P.: Detection and Computational Analysis of Psychological Signals Using a Virtual Human Interviewing Agent. *International Journal of Disability and Human Development 15*, 3 (2014). 3

[Sla09] Slater M.: Place Illusion and Plausibility can Lead to Realistic Behaviour in Immersive Virtual Environments. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences 364*, 1535 (dec 2009), 3549–3557. 2

[Zha03] Zhao S.: Toward a taxonomy of copresence. *Presence: Teleoperators and Virtual Environments 12*, 5 (2003), 445–455. 2