Effects of Behavioral and Anthropomorphic Realism on Social Influence with Virtual Humans in AR

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Abstract

While many applications in AR will display embodied agents in scenes, there is little research examining the social influence of these AR renderings. In this experiment, we manipulated the behavioral and anthropomorphic realism of an embodied agent. Participants wore an AR headset and walked a path specified by four virtual cubes, designed to bring them close to either humans or objects rendered in AR. In addition there was a control condition with no virtual objects in the room. Participants were then asked to choose between two physical chairs to sit on—one with a virtual human or object on it, or one without any. We examined the interpersonal distance between participants and rendered objects, physical seat choice, body rotation direction while choosing a seat, and social presence ratings. For interpersonal distance, there was an effect of anthropomorphic realism but not behavioral realism—participants left more space for human-shaped objects than for non-human objects, regardless of how real the human behaved. There were no significant differences in seat choice and rotation direction. Social presence ratings were higher for agents high in both behavioral and anthropomorphic realism than for other conditions. We discuss implications for the social influence theory [5] and for the design of AR systems.

Index Terms: Applied computing—Law, social and behavioral sciences—Psychology; Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Mixed / augmented reality

1 Introduction

As AR technology advances, virtual environments will be integrated into our world. As these virtual environments gradually become a part of our daily lives, we will interact with virtual humans that reside in these virtual environments. While some virtual humans will be projections of other people (i.e., avatars), others will be embodied agents that are controlled by computers. The media equation theory [18] provides a theoretical foundation to researchers trying to understand embodied agents from this approach. Studies [15, 16] have shown that computer interfaces elicit behaviors similar to those of biological humans, for example by automatically behaving politely. Given that these research from the 1990s showed that interactions with buttons on a flat screen have caused such an elicitation of behaviors, one may easily predict that virtual humans in virtual environments will have a larger influence on real people.

Hoffman and colleagues [9] extended the media equation theory. In their study, participants engaged in a 10-minute conversation with an embodied agent through a computer monitor and were asked to evaluate the conversation by answering questions from the agent itself or by filling out a paper-and-pencil questionnaire. Researchers found automatic politeness towards the virtual human as the participants more highly evaluated the embodied agent when they were questioned by the embodied agent compared to by paper-and-pencil questionnaire. This general strategy of replicating social psychological effects from face-to-face research using new media (e.g., [11,19]) helps us understand the social influence in AR. For example, Miller and colleagues [13], in their first study, examined social interaction in AR with social facilitation and inhibition. They found that participants performed better for easy tasks and worse for difficult tasks when a virtual agent was present. In their second study, Miller and colleagues [13] examined social influence from virtual agents in a setting relevant to personal space [8]. This study was built around the social norms that people maintain a certain distance between each other. When two physical chairs were provided in the room, but one had a seated virtual agent that verbally introduced itself, participants avoided sitting on the chair with the virtual agent, and sat on the empty one. Moreover, when choosing a rotation direction while sitting, participants were more likely to turn around and face the agent than to turn their backs on the agent. While seat choice and rotation angle are certainly constructs related to interpersonal distance, the previous study did not directly measure distance behavior, which is a focus of the current study.

According to personal space research, there are norms which govern how people position themselves in physical contexts with other people. For example, people allow and prefer closer distances for friends compared to strangers [1]. Personal space has been adopted in research with virtual humans in VR [2, 3, 6, 7, 12] and AR [10, 17]. For example, Lee and colleagues [10] used physical distance to measure the effects of virtual human factors such as vibration, gaze, and other movements.

Additionally, we provide a closer look at the actual cause of the social influence based on the social influence theory [5]. According to the social influence theory, behavioral and anthropomorphic realism is required for a virtual human to have social influence. In VR, researchers have examined this level of detail. Bailenson and colleagues [4] conducted an experiment with three representation types with different levels of anthropomorphic realism and four different levels of behavioral realism. They showed that consistency—that is the matching of the two realisms—was an important factor contributing to influence. Von der Puetten and colleagues [22] also manipulated behavioral realism and showed this factor was more influential than agency (i.e., whether a human or computer was driving the virtual human).

In this paper, we will examine both behavioral realism (whether a virtual human moves) and anthropomorphic realism (whether the agent has a human form). We will have four measurements: minimum distance, seat choice, rotation direction, and presence. The details of the measurements will be discussed in the next section. Based on Blascovich's model of social influence [5], as well as the previous empirical findings discussed above, we have generated the following hypotheses:

H1. *A virtual human with higher behavioral realism will induce a larger minimum distance.*

H2. *A virtual object with higher anthropomorphic realism will induce a larger minimum distance.*

H3. *A virtual human with higher behavioral realism will more often be avoided.*

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Figure 1: The types of virtual objects: female human (left), male human (middle), and globe (right). We matched the biological sex between the participants and the virtual humans.

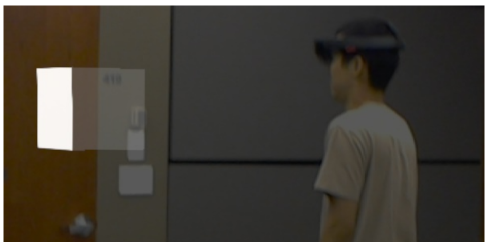

Figure 2: A participant in front of a virtual cube.

H4. *A virtual object with higher anthropomorphic realism will more often be avoided.*

H5. *A virtual human with higher behavioral realism will more often be rotated towards.*

H6. *A virtual object with higher anthropomorphic realism will more often be rotated towards.*

H7. *A virtual human with higher behavioral realism will induce higher presence ratings.*

H8. *A virtual object with higher anthropomorphic realism will induce higher presence ratings.*

2 Method

Participants. We recruited 140 (75 female, 65 male) participants from an undergraduate course and a paid participant pool. One hundred fourteen student participants were given course credits and 26 non-student participants were compensated with a $10 Amazon gift card. The mean age of the participants was 25.4 ($SD = 11.93$). Out of 140 participants, 113 participants had previous VR headset experience and 75 participants had previous AR headset experience.

Materials. Participants wore the Microsoft HoloLens AR headset. The virtual environment for the experiment was built using Unity3D. Vuforia was used for visual tracking to position the virtual objects that were used for this study. The 3D models of the virtual humans were from Rocketbox New Complete Characters HD. We chose one female and one male model to match biological sex of the virtual humans to the participants. A 3D globe model was downloaded from TurboSquid [20]. The model was chosen as the non-human object given its similar amount of color to the humans models and its size was scaled to be similar to that of the human models. See Figure 1 for the virtual objects.

2.1 Design and Procedure

To examine behavioral and anthropomorphic realism, we created three types of virtual objects: agent, statue, and globe. The agent is an animated virtual human, the statue is a virtual human that does not move at all, and the globe is a non-human virtual object that also does not move. Agent had idling body movements and rotated its head towards the participant's as the participant walked around. To avoid uncanny movements such as excessive neck twisting, if the rotation towards the participant required more than 60 degrees of head rotation, the agent's head moved back to its initial pose instead of following the participant. Unlike Miller et al. [13], the virtual human did not speak given that a speaking non-human virtual object may be unexpectedly salient. There were 40 participants for each condition except the control condition without any virtual object which had 20 participants assigned.

Participants were recruited through a website or via email and were instructed to visit our lab. At the lab entrance, an experimenter asked the participants prescreening questions about their health issues. After signing a consent form and a paid participant form, the participants entered a 5.6 m by 6.4 m room with the experimenter where two chairs were placed 1 m apart from each other. A virtual object was registered onto one randomly chosen physical chair. Then an experimenter put an AR headset (i.e. Microsoft HoloLens) on participants, allowing them to see virtual objects and asked them to follow instructions by walking towards four virtual cubes (see Figure 2 for their shape) in clockwise order. During this process, the experimenter did not tell the participant to look at the virtual object, expecting a natural exposure to the virtual object. When the participants reached the last virtual cube, they were asked to stand in front of the two chairs, the place where they initially wore the AR headset.[1] Finally, the experimenter asked them to sit on a chair. Figure 3 describes the path of a participant walking through the virtual cubes and then sitting on a chair.

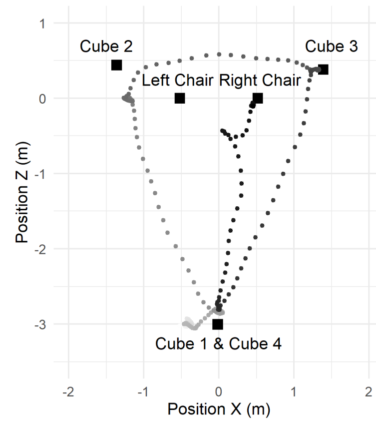

Figure 3: An example of a participant walking towards the virtual cubes and walking behind the chairs. In this case, the participant ultimately sat on the right chair. The first and fourth cubes are at the same position. Lighter dots denote earlier time stamps.

2.2 Measures

Minimum Distance. While walking from the second virtual cube to the third virtual cube, participants walked behind the chairs. At that time, the object minimum distance—the minimum distance between the participant and the virtual object—and the chair minimum distance—the minimum distance between the participant and the closest chair—were measured. Since only the chair minimum

[1] Following Miller et al. [13], we manipulated another variable which turned off the visibility of the virtual objects after the personal space was collected. However, there were no differences in the results based on this variable, and we chose to average across it in order to reduce complexity in this paper. This explains why the experimental conditions have 40 participants per each, while only 20 were assigned to the control condition.

distance can be measured for the control condition—which does not have a virtual object—and given the high correlation between object minimum distance and chair minimum distance ($r = 0.97$) for other conditions, we chose to use chair minimum distance as the minimum distance ($M = 0.59$, $SD = 0.13$) in our discussion. The decision to use the minimum distance, not the average distance, was based on previous research [2, 10] and on the interpretation of personal space as a boundary that people are not willing to have others inside. Larger minimum distance will be considered as larger social influence. This assumption comes from previous work in immersive VR [2, 10] and robotics [14].

Seat Choice. Participants were asked to sit on a chair after walking towards four virtual cubes. With the tracking data of the HoloLens, we observed on which chair the participants sat. We derived whether the participants avoided sitting on the chair with the virtual object on it and will call this *object avoidance* in our analysis (though this does not apply to the control condition). Object avoidance will be interpreted as a reflection of social influence.

Rotation Direction. To sit on a chair, participants had to walk towards it and turn around to sit since the chairs were facing the opposite direction of the participants' walking direction. We detected the direction of the participants' turn with the HoloLens tracking data. From the bird's eye view, a clock-wise rotation was considered as one towards the right chair, and the counter clock-wise was considered towards the left. For the computation of the rotation direction, we used the tracking data of the participants while they were from 0.2 m to 1 m away from the chair on which they sat. For example, if the participant turned counter-clockwise while approaching the 0.2 m point from the 1 m point, the rotation was considered towards the left chair. We will use *forward rotation* to describe a rotation towards the chair with the virtual object and *backward rotation* to describe the rotation towards the empty chair as participants expose their backs to the virtual object when they rotate in this manner. Forward rotation will be considered as evidence of social influence.

Presence. We measured the level of presence with 5 questions on a 5-point Likert scale. For our analysis, given the responses for the questions were highly correlated to each other (Cronbach's $\alpha = 0.812$), we will use the mean value of the 5 responses ($M = 2.04$, $SD = 0.75$). Since participants in the control condition did not see any virtual objects during the experiment, their questionnaire did not include the presence questions.

3 RESULTS

In this paper, we designed four experimental conditions with three virtual objects varying in behavioral and anthropomorphic realism and the control condition without any virtual objects. And, there are four dependent measures: minimum distance, seat choice, rotation direction, and presence. To examine behavioral realism, we will compare agent to statue as they have the same level of anthropomorphic realism. For anthropomorphic realism, we will compare the combination of agent and statue conditions to the globe condition. We will also examine the control condition to provide the baseline, especially for our analysis on minimum distance.

3.1 Minimum Distance

The second column of Table 1 shows the minimum distances per each virtual object type. The agent and the statue condition induced larger minimum distances than the globe and the control conditions, not supporting H1 but supporting H2. Using linear regression with levels of behavioral and anthropomorphic realism as dummy variables, the comparison between agent and statue condition did not confirm H1 ($b = -0.022$, $p = .431$). H2 was confirmed in a linear regression comparing the combination of the agent and statue condition to the globe condition ($b = 0.051$, $p = .046$). Additionally to the examination of the hypotheses, in the comparison between

Object Type	Distance	Avoidance	Rotation	Presence
Agent	0.605 (0.120)	62.5%	57.5%	2.45 (0.955)
Statue	0.627 (0.126)	55.0%	62.5%	1.91 (0.592)
Globe	0.565 (0.146)	52.5%	60.0%	1.78 (0.423)
Control	0.552 (0.142)			

Table 1: The mean (and standard deviation) of the minimum distances per each virtual object type in meters, and the ratio of object avoidance and forward rotation, and means (and standard deviations) of reported levels of presence per virtual object type. For the control condition, only the minimum distance is provided as others were not measured.

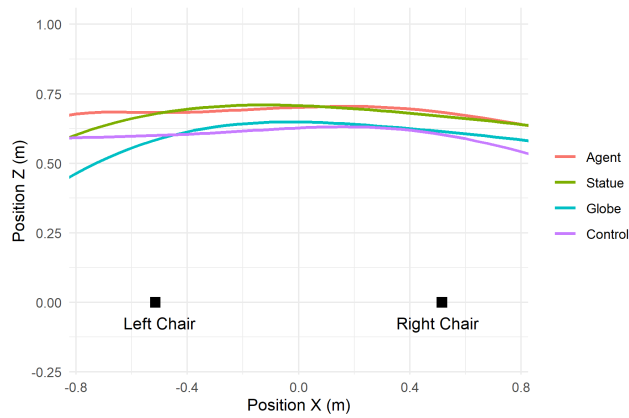

Figure 4: Average paths of participants walking behind the chairs from the second virtual cube to the third virtual cube per condition. The participants walked from left to right.

the globe condition to the control condition, the difference of minimum distance between the conditions was not statistically significant ($b = 0.013$, $p = 0.742$). Figure 4 shows the paths of participants of each condition walking behind the chairs while the minimum distances were measured. The paths were drawn with the generalized additive model with penalized cubic regression spline for smoothing. The x-axis contains the average positions of both chairs and is perpendicular to the z-axis. The model fits the x values of tracking data to the z values. Here, as the test between the globe and control conditions finds, the path for the globe condition is similar to that of the control condition with no virtual object on any chair.

The third column of Table 1 shows how often participants avoided sitting on the chair with a virtual object. As the ratios are very similar among conditions, with the chi-squared test, both hypotheses on behavioral realism (i.e., H3; $\chi^2(1) = 0.206$, $p = 0.650$) and anthropomorphic realism (i.e., H4; $\chi^2(1) = 0.208$, $p = 0.648$) were not confirmed. Since the control condition did not have a virtual object to avoid, it is not included in this analysis.

3.2 Rotation Direction

The fourth column of Table 1 shows how often participants rotated towards the virtual object while sitting on the chair. Using the chi-squared test, both hypotheses on behavioral realism (i.e., H5; $\chi^2(1) = 0.052$, $p = 0.819$) and anthropomorphic realism (i.e., H6; $\chi^2(1) = 0.000$, $p = 1.000$) were not confirmed. For the same reason with seat choice, the control condition that has no virtual object is not included in this analysis.

3.3 Presence

The fifth column of Table 1 reports the means and standard deviations of the reported levels of presence. Using linear regression

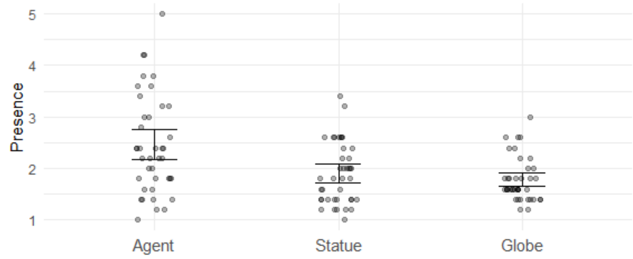

Figure 5: The distribution of presence per each condition with confidence intervals. The confidence intervals were obtained by bootstrapping with the confidence level of 0.95.

with object type as a dummy variable, the hypotheses for behavioral realism (i.e., H7; $b = 0.540$, $p = 0.003$) and anthropomorphic realism (i.e., H8; $b = 0.400$, $p = 0.005$) were both confirmed. The control condition was not included since there is no object to ask its level of presence through questionnaires. Figure 5 depicts the distribution of presence ratings. The distribution demonstrates that the confirmation of hypotheses was driven by the agent condition having a higher rating than both the statue and the globe conditions.

4 Conclusion

In this paper, we examined the social influence from virtual humans from two factors—behavioral and anthropomorphic realism. With minimum distance, we found an effect of anthropomorphic realism. The four hypotheses with other two behavioral measures—seat choice and rotation direction—were not confirmed. With presence as a measure based on questionnaires, hypotheses on both factors were confirmed. In summary, H2, H7, and H8 were confirmed, while H1, H3, H4, H5, and H6 were not.

The result may be interpreted as a higher level of social influence being required for behavioral change compared to the feeling of presence. As the low average level of presence depicts, the interaction between the virtual objects and the participants was minimal. This design choice was driven by the previous studies by Miller et al. [13] which found very high presence levels. Typically, self report measures are easier to demonstrate effects by condition than behavioral measures, likely due to demand characteristics. This effect is particularly salient with presence ratings [21].

The findings relating to object avoidance does not match the results from Miller et al. [13] which found that all participants avoided sitting on a visible virtual human. In our study, the virtual human did not verbally introduce itself, while it did in Miller et al. [13]. While this difference surrounding a verbal interaction may potentially explain the large behavioral difference, the comparison between a speaking and non-speaking virtual human in AR should be an area of potential future study. Unintentionally, due to our recruitment process from a university class on VR/AR, many participants had previous AR experience; some might have read about the Miller et al. study [13], and while our sample was large, the high familiarity with AR research can be considered as a limitation of our study.

The largest implication of this research is showing that features of an AR human change the way people walk in a physical room. As AR use scales up, designers of software and interfaces will need to take into account the effect that rendering virtual objects in AR has on physical locomotion. Future research should continue to explore how virtual objects in AR change physical behavior.

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