Comparing Behavioral and Self-Report Measures of Embodied Agents' Social Presence in Immersive Virtual Environments

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Abstract

Recent work [1, 2, 3] has argued that subjective questionnaires may be ineffective at measuring copresence towards agents and avatars in immersive virtual environments (IVEs). The current work directly compares self-report and behavioral measures of copresence. In two studies, we measured the interpersonal distance between participants and either an embodied tutoring agent or an unfamiliar embodied agent as they walked through an IVE. We found that participants yielded more personal space to embodied tutors compared to other embodied agents in both studies. However, self-report measures of copresence, likability, status, or interest did not reveal any differences between embodied tutors and strangers. These findings suggest that nonverbal behavior may be a more sensitive measure of the copresence and general influence of embodied agents than self-report measures. While alternative explanations for these findings certainly exist, there are clearly strong advantages of using behavioral measures to study copresence as a compliment to other measures. Given that a large portion of current research evaluating collaborative environments utilizes self-report measures only, the current findings are particularly notable.

Keywords

Embodied virtual agents, virtual environments, social presence, copresence, social interaction, virtual reality

1. Introduction

As collaborative interactions between humans and embodied agents become more common, it becomes critical to gain a thorough understanding of the nature of those interactions. In order to do so, reliable measurement tools that quantify the parameters of these interactions (i.e., *copresence* or *social presence*) must be established [4, 5, 6, 7]. Researchers have begun to examine nonverbal behavior as a mechanism to quantify the copresence that embodied agents inspire in humans during collaboration. Such measures include proxemics [8, 9, 10 11], eye gaze [12, 13, 14, 15, 16, 17, 18] and other gestures [19].

Regarding copresence towards embodied agents, we prefer to utilize behavioral measures such as nonverbal gestures, eye-gaze, and task performance [20, 2], as opposed to self-report measures such as questionnaires and anecdotal accounts because behavioral measures have the potential to offer greater sensitivity and reliability over self-report ratings [21]. Moreover, we believe these behavioral measures may be the most appropriate way to detect affective responses [22] that tend to be difficult to explicate verbally or could fall victim to demand characteristics, where participants act in accordance with their perception of the experimenters' goals. In our previous research, we demonstrated that interpersonal distance behavior in IVEs was quite similar to interpersonal distance behavior in physical environments [9, 10]. In other words, people tend to leave a personal space bubble of similar size and shape around people, both virtual and physical alike. In the current set of studies, we use personal space as a metric to compare questionnaire-based and behavioral measures of copresence.

Previous research on spacing behavior in the physical world indicates that individuals leave differential amounts of personal space between themselves and others depending on factors such as familiarity and status. For instance, interactions between familiar persons are characterized by a smaller interpersonal distance than interactions between strangers [9]. Other research demonstrates that individuals leave larger personal space bubbles around those who are high in status than around those who are low in status [23]. For example, observations of student-teacher interaction show this pattern with respect to peer-peer interaction [24]. Specifically, these differences in status among interactants tend to correlate positively with interpersonal distance.

Recent studies by the present authors have validated the use of distance cues to measure copresence behaviors in virtual environments [2, 9, 10]. This approach, combined with our knowledge of real-world spacing behavior, lead us to examine participants' experience of presence with embodied agents during collaborations by comparing their interpersonal distance behavior with an embodied tutoring agent [25, 26] to their behavior with other virtual humans.

The strategy of the current work was to have participants interact with agents who vary in both familiarity and status. The literature on nonverbal behavior in face-to-face interaction discussed in the previous paragraph predicts notable differences in personal space behavior based on these characteristics. Consequently, these differences should carry over to the ways in which participants rate these agents via questionnaires as well as how the participants interact nonverbally with the agents. On the other hand, previous research [2] has demonstrated that questionnaires are not always sensitive enough to measure differences in copresence and affective responses towards agents. Consequently, it may be the case that differences between types of agents will only manifest itself with a nonverbal behavior measure.

In Experiment 1, participants collaborated with a desktop tutoring system based on one previously developed by Nass, Moon, and Carney [27]. Then, participants entered an Immersive Virtual Environment (IVE) and walked around an embodiment of that tutor or around an embodiment of a stranger. Experiment 2 is a replication of Experiment 1. The purpose of reporting both replications is to demonstrate the strength of the current finding, as well as its persistence over slightly changed experimental conditions. In both studies we collected interpersonal distance data as well as questionnaire ratings, including participants' perceptions of copresence, status, interest, and likeability of the embodied agent.

Given the research discussed above, we predicted that participants would respect their tutors' personal space more than another virtual humans' (e. g., a stranger) personal space. Furthermore, we predicted that the behavioral measure of personal space regulation would detect differences between tutors and strangers that self-report measures would not.

2. Experiment 1

2.1. Method

We manipulated the *identity* (tutor vs. stranger) of an embodied agent between participants. For half of the participants, the virtual agent was identified as "the virtual tutor." For the other half, the same virtual agent was identified as "a virtual stranger." The virtual tutor was understood to be a virtual embodiment of the same procedural algorithm that had been used to train participants during a desktop tutoring session earlier in the study. The virtual stranger was understood to be a virtual embodiment of an unfamiliar algorithm.

Participants consisted of 72 psychology students (36 females, 36 males) from the University of California, Santa Barbara who either received course credit for an introductory psychology course or were paid $10 for their participation. Participants' age ranged from 15-30 *(Median = 20*).

The details of the system are fully described in an earlier publication [9], but essentially consisted of a head-mounted display (HMD), dual pipe (stereoscopic) OpenGL PC graphics updated at 60 Hz, and 6DOF head tracking via inertial orientation (Intersense IS300) and video position tracking (WorldViz PPT, millimeter resolution). The explorable space measured 2.6 x 2.5 x 2.5 m (length, width, height). The average latency between head motions and actual update of images in the HMD was 55 ms. Figure 1 illustrates a participant using the IVE equipment in the room where the experiment occurred.

The participant's view of the IVE at the beginning of the experimental session is depicted below in Figure 2. The virtual agent was based on a deformable mesh model representing a Caucasian male. In this study, it exhibited no behaviors other than blinking. The virtual agent always faced the participant's starting position. The participant's eye height was matched to the 1.65 m eye height of the agent.

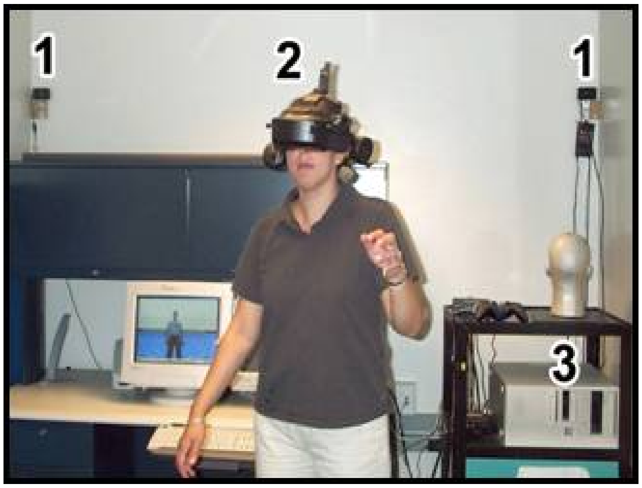

Figure 1. A depiction of our virtual environment system: 1) position tracking cameras; 2) HMD and orientation tracking sensor; 3) image generator.

In the first phase of the study, participants entered a room and sat down with a tutoring algorithm. Half of the participants interacted with a computer program and the other half interacted with a non-linear book fashioned after the "Choose your own adventure" series children books and written to approximately match the interaction with the electronic computer. There were no major differences in the results between these two conditions so this manipulation will not be discussed further in this paper. The tutorial then presented a series of 20 facts about American culture and later tested participants on similar facts. The tutorial was modeled in great detail after the system employed by Nass, Moon, and Carney [27]. During the tutorial there was no representation or embodiment of the tutoring algorithm aside from text appearing on the display.

After completing the tutorial, participants left the room and were escorted to another room with an IVE system. They were then instructed on how the IVE equipment functioned and asked to join a "virtual person" in a virtual environment. Half of the participants were told that they were to meet a virtual embodiment of a computing program. The other half were told they were to meet a virtual representation of an unfamiliar person. Once immersed, participants were first instructed on how to navigate in the virtual world, and received approximately one minute of practice in walking. They then were asked to examine the virtual person by walking up to him: first to the left side, then to the right side, then to the front and center. From this final location, participants were instructed to read aloud a label positioned on the virtual person's chest. Each participant performed this sequence of behaviors twice; each time, a different label appeared on the chest of the virtual agent. In the virtual tutor condition, both labels consisted of familiar keywords sampled from the original twenty facts administered in the tutorial (i.e., prom, kitty). In the virtual stranger condition, labels consisted of novel keywords, functionally and syntactically equivalent to those in the virtual tutor condition (i.e., game, bunny) but not words that had appeared during the tutoring session. In both cases, the label was designed to be large enough that participants could read it clearly from their starting position. The label-reading task has been used previously to facilitate proxemic interaction [9, 10]. In all conditions, while the participant was immersed in the IVE, there was always a single experimenter in the room administering the experiment and ensuring that the participants did not walk into any physical walls.

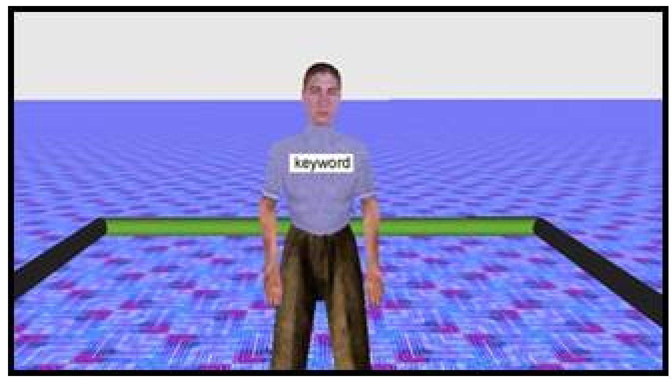

Figure 2. Participant's view of the virtual agent standing within the borders of the virtual room.

We sampled each participant's location at 12 Hz. After completing the two walking trials, participants remained in the virtual environment and responded verbally to a questionnaire with thirteen 7-point items on a Likert-type scale ranging from -3 (strongly disagree) to +3 (strongly agree) with a mid-point of 0 (neither agree nor disagree). This questionnaire was designed to assess perceptions of *copresence* [5, 28], *likeability* of the embodied agent, the perceived *status* of the embodied agent, and finally the degree of *interest* that the agent elicited from the participant. Some of these scales (i.e., copresence and likeability) were previously validated in other work by Bailenson et al. [9], and were designed to explore potential reasons why one might regulate their interpersonal distance behavior in front of an embodied agent. All items appear in Appendix A.

2.2. Results and Conclusions

The tracking equipment automatically and unobtrusively collected position data from the participant as he or she traversed the IVE. We derived a measure of the position tracking data based on the minimum distance, that is, the single shortest line in space between the center of the participant's head and the center of the agent's head during a given trial. We ran an analysis of variance with virtual agent identity (tutor or stranger) as a between-subjects variable and minimum distance as the dependent variable. There were no significant effects. However, as Figure 3 demonstrates, participants appeared to interact with the virtual agent differently over the two walking trials, demonstrating a larger interpersonal distance with the tutor than with the stranger on the first walk but not the second.

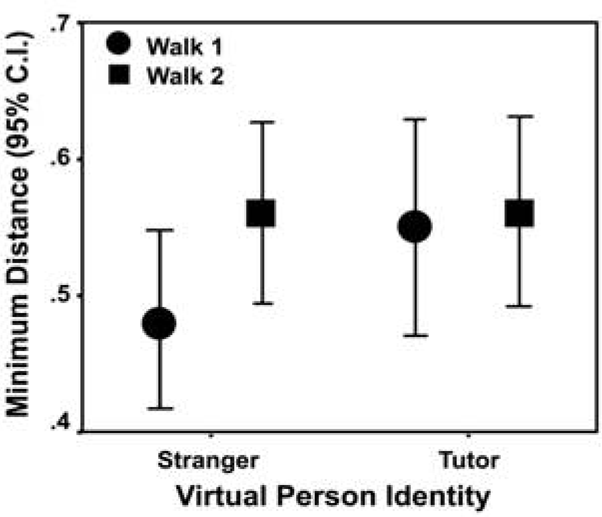

Figure 3. Mean minimum distance to each agent type for walks 1 and 2.

Consequently, we ran a mixed analysis of variance, with trial (first walk vs. second walk) as a within-subjects variable, and virtual agent identity as a between-subjects variable, and minimum distance as the dependent variable. We found a significant interaction between trial and virtual agent identity, $F\ (1,69) = 4.89,\ p<..03$. On the first walk, participants went closer to the stranger. On the second walk, however, there was no significant difference. There were no main effects in this mixed analysis. On their first encounter with the embodied agent, participants maintained a significantly larger bubble of personal space around the virtual tutor than around the virtual stranger. This finding is consistent with past research findings in personal space and suggests that the tendency for participants to give the tutor a wider berth is a reflection of the perception that the tutor was seen as a high status individual [23, 29].

We next examined the participants' responses to the questionnaire items designed to assess perceptions of the embodied agent. Items on three of the four scales (liking, interest, and copresence) were moderate in reliability so we averaged the relevant questions listed in Appendix A, adjusting for the directionality of reverse-coded items. Items comprising the fourth scale containing measures of perceptions of agent status were analyzed separately due to low scale reliability. Nonetheless, the status items produced convergent results. When *explicitly* asked if the virtual agent was higher in social status, there was no difference in ratings based on an independent samples t-test (M = -1.28, SD = 1.37) for the tutor and (M = -1.19, SD = 1.47) for the stranger, p>.8). Similarly, participant ratings of the formality of their relationship with the agent showed no difference between tutor and stranger, using a reverse-code (M = -.278, SD = .198) for the tutor and (M = -.167 SD = .185) for the stranger, p>.6). Also, when asked how comfortable they would be using slang terms when speaking in front of the agent, no difference emerged, adjusting for reverse-coding (M = -1.31, SD = .182) for the tutor and (M = -1.25, SD = .197) for the stranger, p>.8). Furthermore, the ratings of agent status did not correlate with minimum distance, $r= -.072, .058, .184$ respectively, all $p>.1$.

An independent samples t-test showed no difference between the two agent conditions on the likeability scale (α = .52); participants disliked the tutor ($M = -.29, SD = .91$) as much as the stranger ($M = -.56, SD = 1.04$), $p>.2$. Furthermore, likeability did not significantly correlate with minimum distance, $r= -.10$, p>.4. The analyses on the additional items revealed a similar lack of significant difference between the two types of embodied agents. An independent samples t-test showed no difference between the two agent conditions on the interest scale (α = .57); the tutor ($M = .89, SD =.94$) was rated similarly to the stranger ($M = 1.11, SD = 1.04, p>.2$), and interest did not correlate significantly with minimum distance, $r= -.08$, p>.3. Finally, an independent samples t-test showed no difference between the two conditions on the copresence scale (α = .73); the tutor ($M = -1.00, SD =.99$) was rated similarly to the stranger ($M = -.94, SD = 1.06, p>.8$). Copresence did not significantly correlate with minimum distance, $r= .07$, p>.5. In all analyses conducted, there were no notable patterns of gender differences.

Because we obtained a significant difference in the distance participants maintained from the embodied agent only with the first trial in Experiment 1, we revised our experimental measures and collected data from 48 additional participants in Experiment 2, extracting more data from each participant so that it would be possible to examine their personal space behavior in greater detail.

3. Experiment 2

3.1. Method

The design was identical to the design of Experiment 1. Participants interacted with a learning algorithm, and then interacted with either a virtual embodiment of that algorithm or a virtual embodiment of a stranger. There were 32 participants in the tutor condition and 16 participants in the stranger condition. These numbers are disproportionate due to counterbalancing with two different types of tutors. There was no difference between the two tutors, and this effect is not discussed further in this paper. All significant differences in personal space reported hold up if we include only the first 16 subjects run in the tutor condition. However, we include the extra 16 subjects in the analyses in order to increase the probability of finding differences with the self-report data.

Participants consisted of 48 psychology students (27 males, 21 females) from the University of California, Santa Barbara who received course credit in an introductory psychology course for their participation. Participants' age ranged from 18-23 (*Median = 19*).

The materials and apparatuses were identical to those of Experiment 1.

The procedures were identical to the procedures of Experiment 1 except that in order to more thoroughly examine trial order effects, position data was collected over the span of six walking trials. Consequently, there were also six different labels for each participant to read from the virtual agent's chest. As before, labels were either taken from the tutor session (tutor condition) or were random (stranger condition). We administered only likeability and copresence of the original sets of items on the self-reported perceptions of the embodied agent in this study due to time constraints in a given session resulting from the four additional walks around the agent.

3.2. Results and Conclusion

We ran an analysis of variance with virtual agent identity (tutor vs. stranger) as a between-subjects variable, and the average minimum distance of from the six trials as the dependent variable. There was a significant effect of virtual agent identity, $F(1, 42)=8.78, p<.005$. As Figure 4 indicates, participants maintained a larger interpersonal distance with the tutor than with the stranger, both on the first walk and on the other five walks as well. Furthermore, there was a linear trend for participants to leave more interpersonal distance on later walks than on earlier walks, $F(1,44)=6.32, p<.05$.

We next examined participants' ratings of likeability and copresence. First, we examined the reliability of each scale. The two likeability items were low in reliability and, thus, were analyzed separately. Independent samples t-tests for each item showed no difference in likeability between the two conditions; participants disliked the tutor ($M = .72, SD = .81$) as much as the stranger ($M = .56, SD = .81$), $p>.5$, and they reported equal attractiveness ratings for the tutor ($M = -1.16$, $SD = 1.42$) and the stranger ($M = -1.06$, $SD = 1.65$), $p>.8$. Furthermore, the likeability items did not significantly correlate with minimum distance, = $.041$, $p>.7$, and $r= -.078$, $p>.6$ respectively. An independent samples t-test showed no difference on the copresence scale ($\alpha = .59$) between the two conditions; the tutor ($M = -1.43, SD =1.20$) was rated similarly to the stranger ($M = -1.66$,

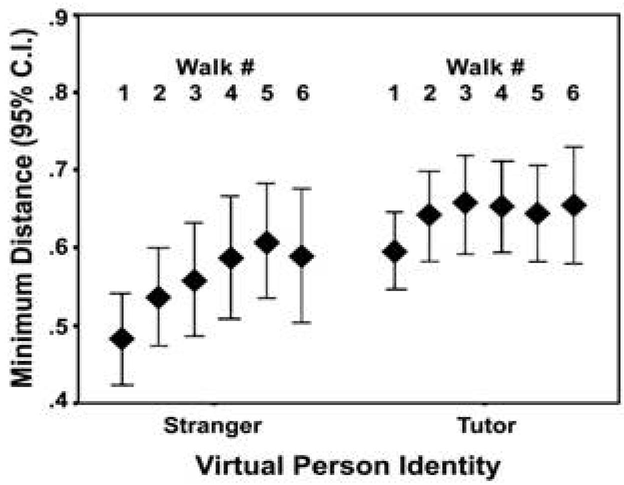

Figure 4. Mean minimum distance for each agent type for walks 1-6.

$SD = 1.09, p>6$). Furthermore, copresence did not significantly correlate with minimum distance, $r= .12$, $p>.4$. In all analyses conducted, there were no notable patterns of gender differences.

Consistent with Experiment 1, participants maintained a significantly larger bubble of personal space around the virtual tutor than around the virtual stranger, and this effect was validated across all six walking trials. However, again, self-report measures on perceptions of the embodied agent did not demonstrate any differences between these two conditions.

4. Conclusions

In the current set of studies, two findings emerge consistently. First, participants who interacted with an embodied tutoring agent in an IVE demonstrate larger interpersonal distances between themselves and the agent than participants who interacted with an unfamiliar embodied agent. Second, this behavioral measure detected differences between tutors and strangers that questionnaire-based measures did not. We discuss each of these effects in turn.

Participants left larger personal space bubbles around embodied tutoring agents than around embodied strangers. There are many explanations for such an effect given what researchers have demonstrated in vivo with regard to interpersonal distance. First, participants may have been more interested in the stranger than the tutor because they had already met the familiar tutor via text interface on a desktop computer, However, this interpretation is in conflict with earlier findings that greater familiarity is associated with closer interpersonal distance [9]. Second, we consider that a tutor is someone who provides knowledge and in doing so is higher in status over those that he or she teaches [27]. Thus, in staying farther away from the tutor than the stranger, participants may have been demonstrating politeness towards their tutors or deferring to their status. Finally, participants may have recognized the word from the tutorial session more easily in the tutor condition, and consequently may have not walked as close to examine the words themselves. However, that explanation would not explain the participants approach differences on the profile sides of the embodied agents. Future research could examine this further by designing interactions with an embodied agent in which personal distance could be more accurately interpreted as a sign of deference, dislike, disinterest, or prior recognition.

In addition, across both studies, there was a trend for participants to maintain a larger personal space bubble between themselves and the embodied agent as the number of trials increased. One potential explanation for this trend is that participants became disconcerted while viewing a virtual agent that did not perform any behavior aside from blinking, and after a number of trials they shied away from the representations. Future research could examine this issue further by varying the level of behavioral realism exhibited by the virtual agent.

However, the goals of the current studies were not to provide an underlying theory of interpersonal distance behaviors within IVEs. Instead, the goals were to demonstrate that behavioral measures were successful in detecting differences in the way participants interacted with different types of agents, while questionnaires alone were not. Consequently, to attempt to measure the nuances of human interaction with agents and avatars using self-report data alone may be short-sighted.

Of course, this claim needs to be *thoroughly qualified* given the current data set. It could be the case that we did not have enough statistical power to properly demonstrate the effects of the self-report data. Furthermore, we may have failed in choosing the correct questionnaire measures—while we attempted to use a wide variety of scales as well as ones with previous validity, it was not possible to examine every single potential set of questions. Indeed, the reliability index on most of our scales was moderate at best. Moreover, the context of the current study—an agent who did talk, express emotion, or walk about—certainly limits our findings to such low-level types of interactions. Finally, it is not clear what the difference in personal space between the two conditions actually represents—status, familiarity, copresence or some other type of affective inclination participants maintained towards the tutor. As a result, it could be the case that the nonverbal behavior has little to do with the copresence, status, likability, or interest self-report measures. In sum, we are not claiming that personal space is a direct proxy for copresence. However, clearly people behave nonverbally towards tutors and strangers differently in IVEs, and this behavior does not map onto any obvious questionnaire rating.

Nonetheless, one thing is clear. In both studies, we observed notable differences in nonverbal behavior towards the two types of agents, but could not match that difference with any type of questionnaire. This is by no means evidence that questionnaires are not useful. However, these data, along with data from previous studies [2], indicate that it is crucial to augment self-report data with some kind of behavioral measure. In future work we plan to examine a larger scope of questionnaires as well as to compare behavioral responses to open-ended self report measures. In addition, we plan to scrutinize more involved nonverbal behaviors, such as eye-gaze and facial expressions.

In addition to providing information to researchers studying presence and copresence measurement, these two studies provide evidence that participants treated embodied agents that they had prior exposure to qualitatively differently than they treated embodied strangers. Given the increasingly common utilization of embodied agents, these results have implications for designers of collaborative systems, in that certain agents may be more appropriate than other types, depending on the type of collaboration. These results suggest that people may initially investigate a virtual stranger more closely than a virtual agent they have prior experience with, even if that experience is not in a virtual environment.

In sum, in these two studies, self-reported perceptions of the embodied agent did not detect differences in our two conditions. This is not to say that one should not utilize self-report questionnaire-based measures in research in this area; countless studies concerning collaborative environments as well as IVEs have demonstrated notable and valuable findings using questionnaire-based and open-ended response forms of self-report data. The purpose of this paper was to provide new empirical data that encourage augmenting questionnaires with behavioral measures when possible. Questionnaires have the advantage of being relatively easy to administer, to validate, to determine reliability through psychometric techniques, and to share with other research groups [30]. However, one of the greatest limitations in questionnaire-based studies is that participants are not always the most accurate judges of their own thoughts and feelings, so they often misreport affective and cognitive responses to stimuli. Therefore, dependent measures based on self-report questionnaires are best used in conjunction with other measures. The convenience of questionnaire-based dependent measures should not come at the expense of measurement power, which behavioral variables, at least in the current study, have as an advantage over self-report.

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APPENDIX A

Social Presence

I perceive that I am in the presence of another person in the virtual room with me.

I feel that the [person OR tutor] in the virtual room is watching me and is aware of my presence.

The thought that the [person OR tutor] is not a real person crosses my mind often.

The [person OR tutor] appears to be sentient, conscious, and alive to me.

I perceive the [person OR tutor] as being only a computerized image, not as a real person.

Likeability

I like the virtual [person OR tutor].

I think the virtual [person OR tutor] is attractive.

Status

The virtual [person OR tutor] is of higher social status than I am.

My relationship with the virtual [person OR tutor] is a casual and informal one.

I would feel comfortable using slang words in front of the virtual [person OR tutor].

Interest

I am interested in the virtual [person OR tutor].

I feel that the virtual [person OR tutor] is interesting to look at.