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Modeling of Pre-Touch Reaction Distance for Faces in a Virtual Environment

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Abstract: One of the most common cues in human relations is the reaction when someone approaches for a touch interaction. While the "before touch" distance has been investigated in daily life scenarios, it has not been studied for virtual environments. The measurements of a pre-touch distance in virtual reality can be applied to study social interactions especially for haptic interactions in virtual spaces where virtual agents interact autonomously with human participants. In the first stage of this study, we collected data to define a pre-touch distance when a virtual agent tries to touch the participant's face. On the basis of these results, we then classified participants into two groups based on preferred pre-touch distance: a "Near" group and a "Far" group. Next, we experimentally investigated the relationship between the participant's perception of an avatar's reaction to touch interaction and their preferred pre-touch distance. The results indicated that the participants felt friendliness to the agent who reacts with shorter pre-touch distance. We also found that the participant's pre-touch distance defined their preferences regarding the agent's behavior: those with a shorter pre-touch distance preferred agents with a closer interaction distance, and those with a longer pre-touch distance preferred agents with a longer interaction distance.

Keywords: virtual environment, social interaction, pre-touch proxemics, social touch

1. Introduction

Research on the nature of interactions in the virtual reality (VR) environment has progressed in recent years thanks to the development of new devices that introduce tactile stimuli for a more natural flow of multisensory information [1] and algorithms that effectively process tactile stimuli using human cognition of the sense of touch [2]. Considering the advances in this field, it is becoming possible to interact with agents in a VR environment using real physical stimuli [3], [4], [5].

However, prior research has focused mainly on the touch and after-touch interactions of virtual agents with participants, with no consideration of the factors involved in the before-touch interaction. One study has revealed that if the reaction distance of a robot before being touched is similar to that of humans, this behavior can help to convey a more natural and human-like impression [6]. In the VR context, simulating interactions between objects and agents by considering physical phenomenon has been studied [1], however, here also no consideration was given to the reaction distance before being touched. Although some research has focused on human-agent proxemics, e.g., personal space in VR [8], [9] and humans' proxemics preferences with regard to robots [10], none of these studies has examined pre-touch situations.

Fig. 1 Pre-touch interaction with an agent.

In this study, we measure the "pre-touch" distance in a VR environment, which can be defined as the distance at which a person usually reacts before being touched. First, we collected data on the distance at which participants begin to feel uncomfortable when a virtual agent tries to touch their face. Then, we analyzed the obtained data and defined the characteristics of the optimal pre-touch distance for VR space. Next, we tested whether a better interaction could be achieved by implementing the pre-touch distance behavior when the participant tries to touch the agent in a VR environment (**Fig. 1**).

This study attempts to answer the following questions:

(1) What is the optimal pre-touch distance for a VR environment?

(2) What impressions do virtual agents give to participants through before-touch behavior when using the obtained pre-

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This paper is an extended version of a previous work by Saito et al. [30] and contains additional references, analysis, and discussions.

touch distance in the same virtual context?

2. Related Works

Edward T. Hall was the first to categorize the relationship between the space and distance at which people feel uncomfortable when they are approached by others [2]. Research on interpersonal space has since been applied to designing the active agent's behavior in VR space [8], [9] and the robot's active behavior in a physical space [12], [13], [14], [15]. Li et al. clarified the difference in proxemics preferences with regard to robots in physical and VR spaces [10]. In particular, interpersonal space plays a fundamental role in the pre-dialogue interaction since the positional relationship and the way individuals approach each other are important factors to consider for establishing a better interaction between humans and artificial agents [16], [17].

Social robots are also used for touch interactions by considering their physical characteristics. Previous studies have revealed that human-robot touch interactions have various positive social effects on the participants [18], [19], [20], [21], [22], [23]. However, these studies focused mainly on after-touch interaction situations and interpersonal distance in dialogue scenarios. In other words, not much effort has been put into pre-touch interaction.

In our previous work, we investigated the pre-touch distance in both human-human and human-robot interactions in the physical space and its application for enhancing human-robot social interactions [6]. However, it is still not clear whether the pre-touch distance measured in the physical space can be applied for virtual agents. In this study, we focus on the pre-touch distance in the VR space and apply the results obtained for pre-touch interaction between humans and virtual agents.

3. Measurement of Pre-Touch Distance towards Virtual Agents

In this section, we describe our data collection of humans' pre-touch distance toward virtual agents.

3.1 Overview

For this data collection, we measured the distance at which a participant began to feel uncomfortable when a virtual agent reached its hand toward their face. We based our method of measuring the distance on the Stop Distance Paradigm [12], [13], [14], [15], [24], [25], which is the most commonly used method for measuring interpersonal distance in social interactions. In this method, the virtual agent gradually moves its hand closer to the participant's face and the distance at which the participant starts to feel uncomfortable is recorded. The pre-touch distance in VR space was calculated as the distance between the end of the agent's right-hand middle finger and the participant's viewpoint (coordinates at the center of a head-mounted display [HMD]).

To investigate the effect of the avatar's gender on the participants' pre-touch behavior, we measured the pre-touch distance using two types of agents: one with a male appearance and the other with a female appearance. A total of 20 individuals participated in the data collection (ten males and ten females aged 18 to 24).

Fig. 2 A view of the experimental setting.

Fig. 3 Appearance of the agents.

3.2 System

We used Unity, a game development platform provided by Unity Technologies, to develop the 3D model of the agents, their movements, and the virtual environment. We also implemented functions for stopping the approach of the agent's hand, by measuring the distance between the participant and the agent.

3.2.1 Environment

To implement the VR environment, we used Oculus Rift, an HMD for virtual reality. By linking it with Unity, the position and orientation of the HMD are reflected in the VR space, and people can feel as if they are simultaneously in the VR space.

The experiment was performed while the participant was sitting on a chair, wearing an HMD, and holding the controller (**Fig. 2**). In the data collection stage, the controller used for stopping the agent's hand from approaching the participant's face was the Xbox controller sold by Microsoft. The participant was able to press the button at any time to record the pre-touch distance measured at that moment.

3.2.2 Virtual Agents

Two animated 3D models, one of a man and one of a woman (Unity Assets Store), were used as the agents to measure the pre-touch distance (**Fig. 3**). Both agents were capable of performing the required movement for data collection, namely, reaching towards a participant's face.

3.2.3 Touching Behavior

The touching behavior is defined as follows: while the participant is sitting, the agent is standing and reaches their right hand

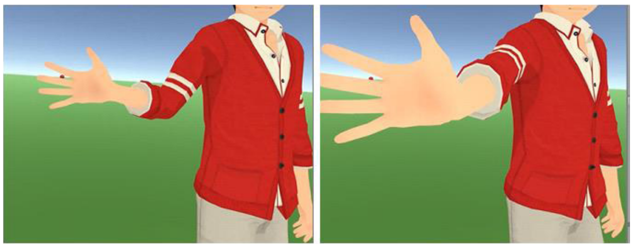

Fig. 4 Approach of the hand.

close to the participant's face from various angles (**Fig. 4**). Considering the direction of the participant's face, there are 19 angles over the vertical direction (from −45 to 45 degrees in 5-degree increments) and 13 over the horizontal direction (from −30 to 30 degrees in 5-degree increments). A total of 247 angles were set in random order.

The agent's hand was always placed 70 cm away from the participant's face at all angles, and was programmed to approach it as fast as possible within five seconds, which means a constant movement speed of 14 cm/s. We designed the touching motion for the agent's palm to be closest to the participant's face by adjusting the approaching angle of the touching motion. The initialization of the touching behavior (start/stop) and the agents' hand position could be set with a button on the participant's controller.

3.3 Procedure

After filling in the consent form for taking part in the experiment, the participants put on and adjusted the HMD and then listened to our explanation of the experiment. When they pressed the button on the controller, the agent appeared with the position of its right hand fixed. After confirming the position of the hand, the participants pressed the button to initiate the agent's touching motion. They were able to stop the agent's hand by pressing the same button again at the moment they began to feel uncomfortable. Then, the system measured the distance between the participant's face and the palm of the agent's hand. After finishing the measurement procedure for all the target angles, there was 3-minute rest period, and then the agent's gender was switched and the measurements were performed again.

4. Analysis of Interpersonal Distance Data for Touching Behavior

In this section, we present the processing method and data analysis results of the pre-touch distance data measured in the VR space. Then, on the basis of these results, we create a model defining the distance at which the agent in the VR space should react when a hand is approaching its face.

4.1 Data Processing

When the participant stopped the approaching hand of the agent by using the controller, the distance between the participant's face based on the HMD or namely the distance between the agent's hand palm and the HMD camera position in the VR environment, along with the angle and the agent's gender. When the agent's hand was stopped by the participant at an unintended distance due to an operational error, e.g., pressing the button repeatedly, the data was not included in the analysis.

Table 1 Four-factor ANOVA results (p < .05 in bold).

Factor	p-value	Factor	p-value
Gender of participants (PG)	0.536	AG×LR	0.758
Gender of agent (AG)	0.785	TB×LR	0.910
High low (HL)	**0.024**	PG×AG×HL	0.968
Left right (LR)	**0.019**	PG×AG×LR	0.957
PG×AG	0.186	PG×HL×LR	0.156
PG×HL	0.182	AG×HL×LR	0.469
PG×LR	0.888	PG×AG×HL×LR	0.917
AG×HL	**0.010**		

4.2 Analysis Results

4.2.1 Data Overview

In the acquired dataset, we measured 4,934 data points for the ten male participants (with male agent: 2,467 points; with female agent: 2,467 points) and 4,918 points for the ten female participants (with male agent: 2,457 points; with female agent: 2,461 points). The average pre-touch distance for all 20 participants was 17.93 cm (SE = 1.98 cm). The average pre-touch distance obtained for the physical space in our previous work was 20 cm [6].

In other research, the effects of the participant's gender, angles/speed of the approaching hand, and habituation were considered for defining a pre-touch reaction distance in human interaction [6]. Therefore, we also analyzed the data with a focus on gender, angles, and habituation effects. We did not consider the agent's touching speed because it was constant during data collection.

4.2.2 Verification of Approach Angle and Gender Effects

First, we conducted a four-factor ANOVA considering the participant's gender (male/female), agent's gender (male/female), vertical direction (upward/downward), and horizontal direction (left/right). The results are shown in **Table 1**.

There were significant differences in the main effects of the vertical and horizontal factors and in the interaction of the vertical factor and gender of the agents (**Figs. 5** and **6**). Regarding the horizontal factors, the pre-touch space was significantly longer from the left side (18.4 cm) than from the right side (17.4 cm). The reason for this could be the perceived agent's body proportions as seen from the participant's visual field. When touched from the left side, the agent's body was in front of the participant (Fig. 4), but when touched from the right side, the agent's body was mostly out of sight, which may have influenced the pre-touch distance. The difference in the position of the agent's body for each side occurred because the virtual agent used its right hand in both the left and right approach. This implies that the agent had to be repositioned for meeting the distance conditions defined in the

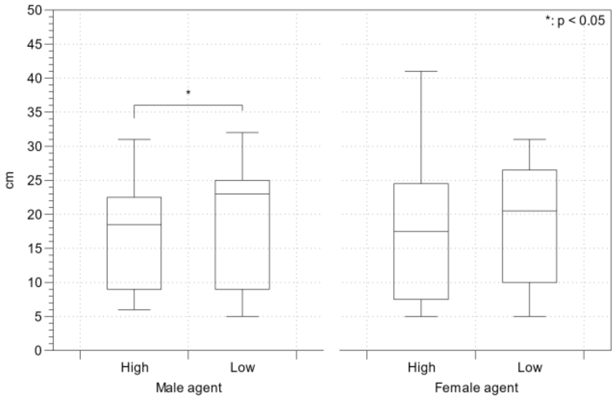

Fig. 5 Variation in pre-touch distance due to agent's gender and vertical angles.

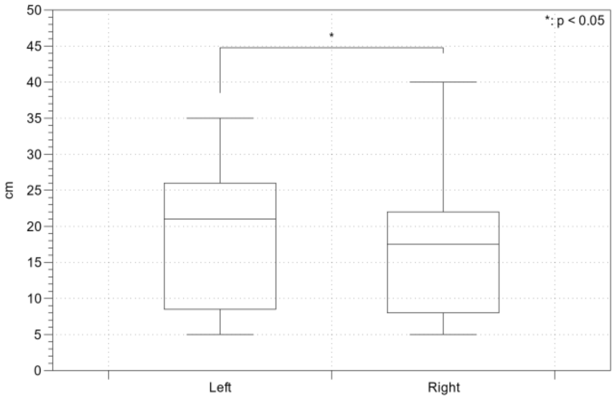

Fig. 6 Changes in pre-touch distance caused by left-right directional factors.

Table 2 Three-factor ANOVA results ($p < .05$ in bold).

Factor	p-value	Factor	p-value
PG	0.486	PG×T	0.644
AG	0.104	AG×T	0.166
T (Time elapsed)	0.449	**PG×AG×T**	**0.043**
PG * AG	0.066		

procedure. Also, the reason for using the avatar's right hand in the data collection was that most of the people in Japan are right-handed and in particular all participants were right-handed. This allowed us to consider the usual pre-touch interaction situation.

Multiple comparisons with the Bonferroni method revealed that when the agent was a male, the pre-touch distance was significantly longer when the agent approached from the lower side than from the upper side ($p = .010$, 19.3 cm for the lower side and 16.8 cm for the upper side). These results indicate that the touch angle, in combination with the agent's gender, influences the pre-touch distance. On the other hand, the difference in the absolute values was found to be around 1 to 2.5 cm.

4.2.3 Verification of Habituation Effects

Next, to test the effects of habituation, we conducted a three-factor analysis considering the participant's gender (male/female), the agent's gender (male/female), and data collection duration (first ten/final ten). The results are shown in **Table 2**. Significant differences were found in the interactions of participant's gender, agent's gender, and tryout factors (**Fig. 7**). Multiple comparisons with the Bonferroni method revealed that the first ten trials showed a significantly longer distance than the final ten trials when the participant was a male and the agent was a female ($p = .028$, 22.3 cm for the first ten trials and 18 cm for the final ten trials).

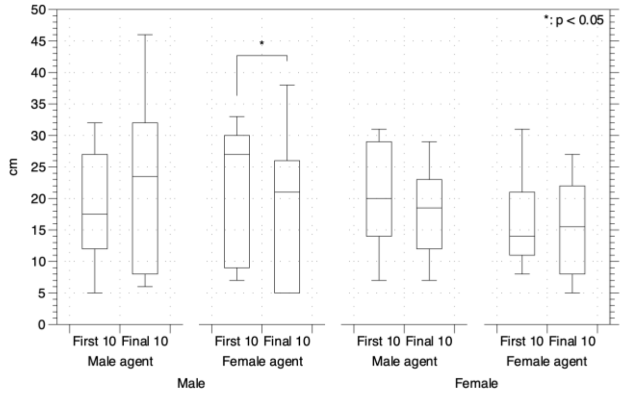

Fig. 7 Change in pre-touch distance due to habituation.

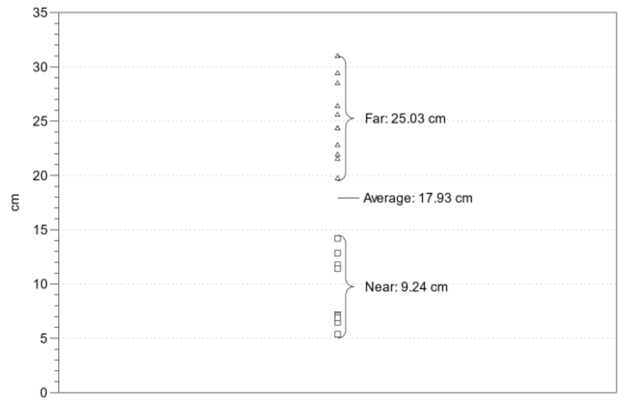

Fig. 8 Clustering pre-touch distance based on the mean.

4.3 Analysis of Trends in Pre-touch Distance

We hypothesized that the average pre-touch distance of each participant could be allocated into two groups with the overall average (17.93 cm) as the boundary (**Fig. 8**). Thus, we performed clustering by the k-means method with two clusters (Near: lower than average and Far: higher than average). Results showed that the average pre-touch distance obtained for the Near group was 9.24 cm and for the Far group was 25.03 cm, which suggests that the pre-touch distance preferred by humans is not necessarily uniform. Therefore, in the second phase of our study, we used the pre-touch distance mean of each group to determine what the proper reaction of an agent should be to a touch behavior.

5. Design and Evaluation of Agent's Response to Human's Touching

5.1 Hypotheses and Predictions

Related work on human-robot pre-touch distance has shown that, in human-robot interactions, the robot gives a more natural impression if it reacts according to the average human pre-touch reaction distance [6]. However, it is not clear whether the pre-touch distance data collected from humans is similarly effective for agents in the VR space.

Our data collection results suggest that a reaction behavior can be defined by at least two different pre-touch distance groups (Near/Far) with the average distance of both groups as a threshold. When a virtual agent reacts to a touch behavior based on the analysis of human interaction, we can expect the virtual agent to give a better impression by having people approach at a closer distance, similar to the human-human interpersonal distance. We can also expect that people would prefer an agent with pre-touch behavior similar to their own pre-touch distance. On the basis of these considerations, we will verify the following predictions:

Prediction 1: The shorter the agent's pre-touch distance, the participants will perceive more likeability to the agent.

Prediction 2: The shorter the agent's pre-touch distance, the participants will feel that the agent perceives more likeability to them.

Prediction 3: People will prefer an agent whose pre-touch reaction behavior is similar to their own.

5.2 Conditions

In this experiment, we considered the pre-touch distance (within-participant, three conditions: Near/Average/Far), the agent's gender factor (between-participant, two conditions: male/female), and the participant's gender factor (between-participant, two conditions: male/female). The details of each condition in the pre-touch distance factor are as follows.

Near condition: The Near group average obtained in data collection (9.24 cm).

Average condition: The Average of all participants in data collection (17.93 cm).

Far condition: The Far group average obtained in data collection (25.03 cm).

5.3 System

To verify our hypotheses, we performed an experiment in VR space using the system we created for data collection. We attached a wireless controller to the right hand of the participants for reflecting their position in the physical space into the VR space and then had participants reach their hand toward the virtual agent's face. Both the participants and their avatars were in a standing position while the virtual agent was in a sitting position. **Figure 9** shows the view of the participants when they are approaching their hands to the agent. We added figures with a third person view from the system as a reference. In the second experiment, the virtual agent(s) will be looking in different directions due to the participants' standing positions, but the agents react based on the threshold as implemented.

5.4 Participants

Twenty-eight participants (14 males and 14 females) aged 18 to 24 years participated in this experiment.

5.5 Procedure

First, participants filled in a consent form for taking part in the experiment. Then they put on and adjusted the HMD and listened to our explanation of the procedure. At first, a simplified version of the data collection procedure described in Section 4 was performed in order to obtain the pre-touch distance for each participant. Specifically, the resolution of the angle at which the hand of the agent approached the participant was changed from 5 degrees to 15 degrees, and the pre-touch distance was measured for a total of 35 angles.

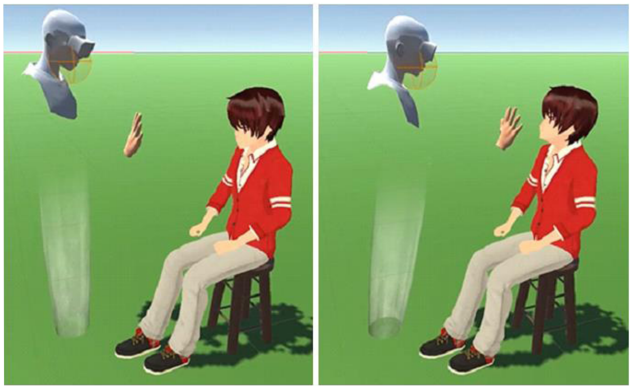

Fig. 9 Pre touch interaction between participant and agent.

After collecting the data, we started the experiment. A male or female agent was sitting in the VR space. The participant could move his/her right hand towards the agent's face at any time. The agent would look at the participant's face when his/her hand approached within a certain distance from the agent's face. This distance was measured between the participant's hand and the closest point selected from 7 agent's face parts: center of forehead, center of eyes, center of right and left cheek, center of right and left side of the head and jaw. We explained to the participants that this action was an indication of restlessness or discomfort, and asked them to stop the approach as soon as the agent's reaction was observed.

Under each condition, the distance at which the agent responded to the participant's hand was determined on the basis of the conditions presented in Section 5.2. Participants moved their hands close to the agent's face nine times from different angles (vertical directions: top, frontal, bottom, and lateral directions: right, frontal, and left combinations) and observed their responses. The order of approaching angles is counterbalanced. After the experiment, the participants filled in a questionnaire, the details of which are discussed in the next section. This procedure was performed for all the pre-touch distance conditions, and after a short break, it was performed again with an agent of a different gender.

5.6 Measurement

We administered questionnaires and interviews to gauge the participants' perceptions as follows.

Participants' likeability towards the agent: Using the Likeability item of Godspeed questionnaire series [26], we asked participants to evaluate the friendliness and kindness of the agents. Each item was estimated with 1-to-7 scale questions where 1 was mostly negative.

Perceived agent's likeability towards the participants: We prepared items to estimate the perceived agent's feelings of likeability, closeness, and friendliness toward participants based on the

Likeability items of Godspeed: like-dislike, friendly-unfriendly, kind-unkind, pleasant-unpleasant and nice-awful. Each item was estimated with 1-to-7 scale questions where 1 was mostly negative.

Pre-touch distance match: After the experiment was completed, we interview the participants to check which of the Near/Average/Far conditions was preferred, ordering them from the most liked to least liked. The order of the conditions was randomized. We compared the interview results with the pre-touch distance group (Near/Far) of the participant obtained in the data collection.

6. Results

Our analysis of the data collection before the experiment showed that there were 14 participants in the Near group (seven males and seven females) and 14 participants in the Far group (seven males and seven females). The classification was made considering the average value of the data collection before experiment for each participant. The following is a detailed description of the results obtained.

6.1 Verification of Prediction 1

We performed a four-factor mixed ANOVA (agent pre-touch distance (AD), participant pre-touch distance group (PD), agent gender (AG), and participant gender (PG)) on the participants' likeability questionnaire results (**Table 3**). We found there was a significant difference in the pre-touch distance factor of agents. The results obtained with multiple comparisons on agent pre-touch distance (**Fig. 10**) showed that there was a significant trend between the Near condition and the Far condition ($p = .083$), and that the Average condition was significantly higher than the Far condition (Average > Far: $p = .012$). There was no significant difference between the Near and Average conditions ($p = 1.000$). Therefore, prediction 1 was partially supported.

6.2 Verification of Prediction 2

We performed a four-factor mixed ANOVA (agent pre-touch distance (AD), participant pre-touch distance group (PD), agent gender (AG), and participant gender (PG)) on the agents' likeability questionnaire results (**Table 4**). Similar to the participant's likeability, we found a significant difference in the agent's pre-touch distance factor. The results of multiple comparisons on the agent's pre-touch distance (**Fig. 11**) showed that the Near condition had significantly higher values than the Far condition (Near > Far: $p < .001$), the Near condition had significantly higher values than the Average condition (Near > Average: $p = .002$), and the Average condition had significantly higher values than the Far condition (Average > Far: $p < .001$). Therefore, prediction 2 was supported.

6.3 Verification of Prediction 3

Table 5 shows the ratio of the participants' pre-touch distance group (Near/Far) and the preferred agent's pre-touch reaction distance (Near/Average/Far). A chi-square test showed that there was a significant difference among the conditions ($x^2(2) = 7.067$, $p = .029$). The residual analysis showed that the Near distance group significantly preferred the Near agent's reaction distance over the Far one. Also, there was a significant trend in the Far distance group to preferring the Far agent's reaction distance over the Near one. This indicates that prediction 3 was partially sup-

Table 3 Participants' likeability to agents ($p < .05$ in bold).

Factor	p-value	Factor	p-value
AD	**0.014**	PD×PG	0.729
PD	0.773	AG×PG	0.715
AG	0.866	AD×PD×AG	0.706
PG	0.878	AD×PD×PG	0.816
AD×PD	0.247	AD×AG×PG	0.962
AD×AG	0.061	PD×AG×PG	0.484
AD×PG	0.971	AD×PD×AG×PG	0.345
PD×AG	0.316		

Table 4 Agent's likeability to participants ($p < .05$ in bold).

Factor	p-value	Factor	p-value
AD	**<0.001**	PD×PG	0.984
PD	0.407	AG×PG	0.194
AG	0.461	AD×PD×AG	0.625
PG	0.954	AD×PD×PG	0.135
AD×PD	0.707	AD×AG×PG	0.212
AD×AG	0.216	PD×AG×PG	0.401
AD×PG	0.630	AD×PD×AG×PG	0.287
PD×AG	0.791		

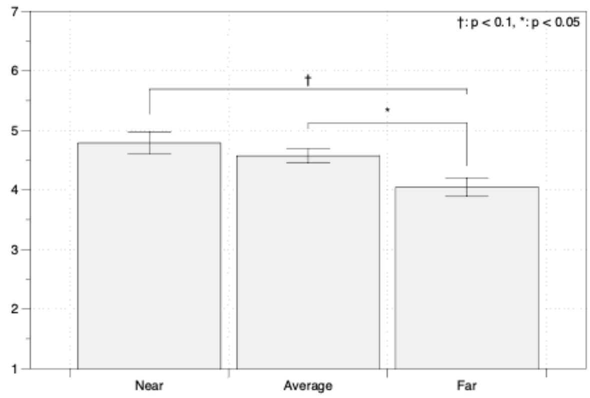

Fig. 10 Questionnaire results of participants' likeability to agents.

Table 5 Pre-touch distance and preference of participants (∗: $p < .05$, +: $p < .10$).

		Pre-touch distance conditions (agent)		
		Near	Average	Far
Pre-touch distance groups (participants)	Near	5*	7	2^{+}
	Far	0*	8	6^{+}

ported.

7. Discussion

7.1 Application of Pre-touch Interaction in VR Space to Pre-touch Interaction in Physical Space

The results of the data collection in VR space in this study are similar to those in the physical space, although there are some differences in the data collection. In this paper, we only dealt with the pre-touch distance around the face. In future work, by collecting and comparing the pre-touch distance data of additional body parts, it will be possible to investigate in more detail how the cognition of the pre-touch interaction differs between VR space and physical space for each separate part of the body.

If we can approximate the pre-touch distance for the physical space by adding certain coefficients to the pre-touch distance in the VR space, it should be possible to approximate a pre-touch distance to a body part that would be difficult to actually measure in reality (including from an ethical point of view) by implementing the conditions in a VR environment. In addition, in VR space, it is easier to set and modify the appearance, arm trajectory, speed, and other characteristics of an agent trying to touch a human than in the physical space. Therefore, this research should contribute to the development of a pre-touch distance model that takes into account various factors of the human body.

7.2 Modeling of Pre-touch Reaction Distance

In this study, we used thresholds of pre-touch reaction distances for the agents to react toward touching. While this simple modeling provided interesting knowledge about participants' perceived feelings in our experiments, it is still unknown whether a threshold-based approach, where threshold distance is the same from any angle, can be extended to reproduce an accurate boundary for a pre-touch reaction distance area. This means that having a spherical shape might not be the most accurate boundary. For example, the plotted averaged data of each angle for Near, Average and Far Groups showed different boundary shapes for each group, as we can see in **Fig. 12**.

Therefore, we conducted a surface fitting with a cubic spline given by the Eq. (1).

$$z = a + b * x + c * y + d * x^2 + f * y^2 + g * x^3 + h * y^3 \quad (1)$$

where x is the vertical angle, y is the horizontal angle value, and z is the estimated pre-touch reaction distance. We used the Akaike Information Criterion (AIC) to adjust each model's likelihood for obtaining the coefficients for each group (**Table 6**). **Figure 13** shows the surface fitting result of the far groups' data points from the data collection.

The surface curves between the averaged and far groups were similar, but the near group showed a different shape. Moreover, the coefficient of determination (R^2) of the near group was relatively low compared to the other two groups. However, the value was still more than 0.50, so it would be useful to reproduce more accurate pre-touch reaction boundaries in human-agent touch interaction.

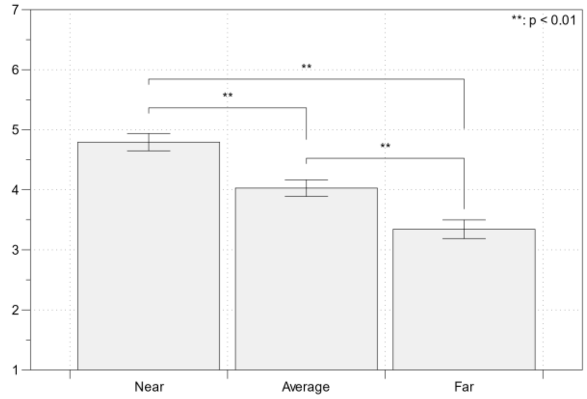

Fig. 11 Questionnaire results of perceived agent's likeability to participants.

Table 6 Coefficients of each group.

	Near	Average	Far
a	8.7E00	1.7E01	2.4E01
b	–7.3E-02	–1.7E-01	–2.0E-01
c	–7.5E-02	–1.4E-01	–1.5E-01
d	–5.7E-02	–5.1E-02	–3.8E-02
f	–6.1E-02	–2.3E-02	–1.4E-02
g	1.4E-03	1.2E-03	8.3E-04
h	–5.4E-03	–2.8E-04	4.8E-05
R^2	0.53	0.74	0.71

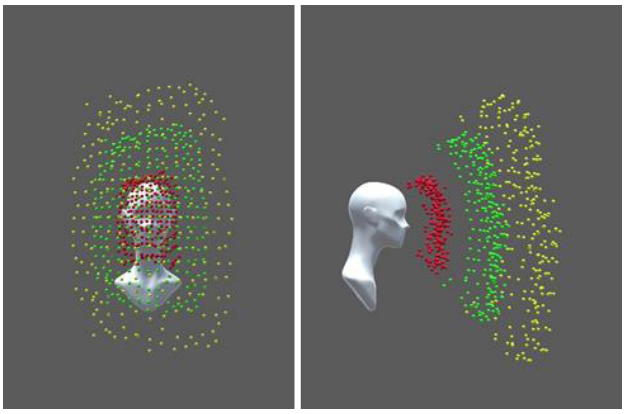

Fig. 12 Averaged distance data of each angle in each group from the data collection (red: Near, green: Average, yellow: Far).

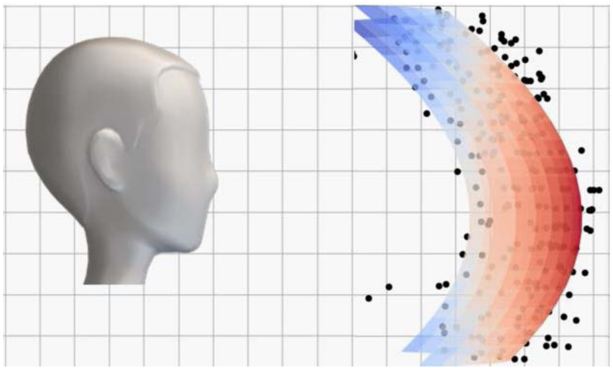

Fig. 13 Fitting result of the far group.

7.3 Distribution of Pre-touch Distance in Physical Space

In our previous study on pre-touch interaction in the physical space, the overall mean of pre-touch distance was calculated but

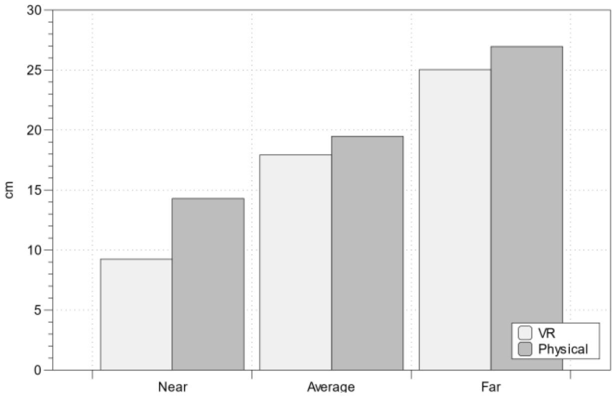

Fig. 14 Pre-touch distance in VR and physical environments.

did not distinguish between Near/Far groups. Therefore, when the analysis performed in the current study was implemented using the previous study data, the generated clusters and averages for the below and above average groups were different (Near: about 14 cm; Average: about 20 cm; Far: about 27 cm). **Figure 14** shows the pre-touch distance measured in the VR space as well as in the physical space.

When we compared the data from the two studies, it was clear that the pre-touch distance in the physical space was slightly longer than that in VR space. For the average and far groups, distances in the physical space were longer than those in the VR space by about 2 cm. In the near group, the distance difference was about 5 cm. Further investigation is needed to clarify whether this difference is due to the HMD view or to an actual difference in the environment. On the other hand, there were also common aspects to the pre-touch distance for VR and physical space. We found that the preferred pre-touch distance in both spaces became longer as we got closer to the facial area. In other words, the greater the distance, the closer the pre-touch distance between VR and physical spaces. At the same time, common cognitive tendencies such as clusters based on the preferred pre-touch distance were similar in both spaces. In future work, we will examine more detailed differences in the pre-touch perceptions by comparing the measured distances in the physical space and VR space using the same participants.

7.4 Expression of Intimacy in Pre-touch Interaction Based on Differences in Pre-touch Distance

In our experiments, we found that the agents who reacted at a closer pre-touch distance conveyed a friendlier impression to the participants. In the past, researchers have tried to build up relationships between humans and robots through long-term interaction, where the interaction content or robots' behaviors gradually changes in order to express familiarity [27], [28], [29]. In this context, as part of the behavior to express such emotions, we can expect to increase friendly relationship impressions by gradually decreasing the pre-touch distance in human-robot interactions.

7.5 Effect of Habituation and Gender on Pre-touch Distance

The analysis conducted in Section 4 revealed differences in pre-touch behavior stemming from the agents' gender. In particular, regarding the changes related to habituation, different trends were observed for the participant genders. We believe that agents can help create a friendlier relationship if we define a behavior that considers the changes in the pre-touch distance caused by the relationship between habituation and participants' gender.

7.6 Limitations

The findings obtained in this research have some limitations. First, we collected and validated data with relatively young participants, but pre-touch distance may differ depending on participants' age and body size. In this study, the number of classes of pre-touch distance was simply assumed to be less than, equal to, or larger than the average, but further classification should be possible by gathering additional data.

Second, for the data collection in the current study, we used agents with anime-like appearances. However, as above, the preferred pre-touch distance may also vary depending on the appearance, age, body size, and social impressions (liking or disliking) of the agent. Therefore, when applying the findings of this study to the pre-touch interactions of virtual agents, it will be necessary to consider the effects of the agent's appearance on a participant's behavior.

Finally, the agent was using its right hand for the approach. Considering that right-handed people are majority in Japan and all the participants were right-handed, having the same hand for the agent allows us to cover the most common pre-touch interaction situation. Still, the pre-touch distance may also be affected by the agent handedness and how this defines its position relative to the participant in a pre-touch interaction.

8. Conclusion

In this study, we first collected data on pre-touch behavior in order to investigate the potential natural interaction between a human and an agent in the VR space. The distances at which a participant begins to feel uncomfortable when an agent's hand approaches their face was collected at different angles, and we clarified that the pre-touch distance changes depending on the appearance and touch angle of the agent. We also found that the pre-touch distance measured in the physical space was similar to that obtained in the VR space. Similarly, the pre-touch distance in both spaces could be classified into two types: near/far.

Next, we conducted an experiment to determine the impressions that changes in pre-touch distance could have on participants in a touch interaction with an agent in the VR space. Results showed that an agent that responds at an average pre-touch distance gives a more familiar and friendlier impression than an agent that reacts at a longer pre-touch distance; and the closer the agent's pre-touch distance is, the friendlier the agent appears to the person. It also became clear that a person with a closer pre-touch distance prefers an agent with a similar close pre-touch distance. The same is true for a person with a longer pre-touch distance.

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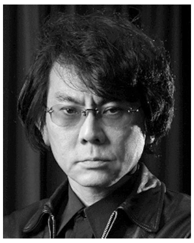

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