Influence of the Height of a Robot on Comfortableness of Verbal Interaction

Yutaka Hiroi and Akinori Ito, *Member, IAENG*

***Abstract*—We investigated the effect of height of a robot on comfortableness of verbal interaction with the robot. We created a robot whose height could be changed continuously, and carried out dialog experiments with humans at varying robot heights. We employed 19 participants to evaluate "comfortableness of dialog", and investigated the height at which the participants felt the dialog was most comfortable. Next, we investigated differences of dialog comfortableness when the height of the robot was changed. Finally, we changed the distance between the participant and the robot and observed whether the dialog comfortableness changed or not. The experimental results yielded the following three guidelines for designing the height of a communication robot. First, the optimum height of a communication robot is about 300mm lower than the eye height of the user. Second, the comfortableness of dialog with the robot degrades when the height of the robot is 200mm lower or 300mm higher than the optimum height. Third, the distance between the robot and the user does not affect the optimum height of the robot.**

***Index Terms*—Robot, Human-robot interaction, Human interface, Speech recognition, Verbal interaction, Robot height, Dialog comfortableness**

I. Introduction

For a long time, the concept of robots cohabitating and communicating with humans in the same environment was a matter of fiction. In recent years, due to the advancement of robotics technology, robots that are actually able to communicate with people have been developed, such as PaPeRo [1], ROBOVIE [2], ASIMO [3], and HERMES [4]. Such robots that can communicate with humans through various means are expected both to assist humans and cohabitate with them in the future. Such robots employ various modalities in order to communicate, including verbal interaction, gestures, and other types of sensor information. In this paper, we focus on verbal communication including spoken dialog, which is the most important modality in human-hobot interaction (HRI).

Attempts to use spoken dialog in HRI began in the late 1990s and early 2000s [5]–[7]. Since then, spoken dialog has been used in many studies to control robots. Other factors, as well as voice recognition and synthesis, affect the naturalness and comfortableness of spoken dialog with robots [8], and do non-linguistic information such as gestures [9], [10], line of sight [11], and facial expressions [11], [12] have also been incorporated into dialog systems.

Interaction is significantly affected by not only multimodal behavior such as gestures and line of sight but also the actual shape of the robot. For example, if the robot is too large or too small, smooth interaction is expected to be difficult. Robots such as ASIMO have the ability to interact with and participate in spoken dialog with the user, but such robots come in different sizes. Many humanoid robots are the size of a child, but there is no evidence to suggest that a similar size is appropriate. Although a robot's height is a key factor affecting the comfortableness of HRI, the effect of height has not been studied.

In a related study, Lee et al. [13] designed a robot for investigating long-term human-robot interaction. In their study, they examied the height of the robot, using three kinds of robot with different heights (1120mm, 1280mm and 1420mm), and found that the most preferred one had a height of 1420mm. However, they did not investigate the effect of height in detail and the experiment was preliminary, so their result may not be applicable to other kinds of human-robot interaction.

Hiroi et al. examined the relationship between the size of a robot and the psychological sense of fear [14]. In their study, robots of various sizes were moved toward the experiment participants at a speed of 400mm/s from a distance of 3m, and the relationship between the distances at which the participants felt uncomfortable and the size of the robot was examined. The results revealed that the larger the robot, the greater the distance at which the participants felt uncomfortable. The study clearly showed that the size of a robot has a psychological effect on the people in the surrounding area, and so this effect should be considered when designing robots. However, the study only looked at the impressions of participants in relation to a robot's movement toward them; it did not clarify what kinds of effect robot size has on interaction, etc. Furthermore, it is known that height affects impressions in communication between humans, and that the social impact of this is reflected in annual income, etc. [15]. Moreover, the robots used by Hiroi et al. in the aforementioned study were white and cuboid in shape, but for actual interaction a shape similar to that of a human is required [16]. Therefore, it is important to study the relationship between the size of a robot and interaction using human-like robots.

Accordingly, in this paper, we study the effect of robot size on verbal interaction [17] such as an exchange of short phrases. In interacting with a robot, it is normal for the human and robot to face each other, and so the "size" of the robot includes its height and width. Of these two factors, we focus on robot height in this study because it offers greater flexibility with height from a design perspective [14]. In this study, we conducted an experiment using a small communication robot [18] as the robot for interaction and, instead of varying the robot size, we vary the height at which the robot is installed.

Changing the robot's "height" rather than "size" and using a relatively small robot could be considered a problem

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Y. Hiroi is with Faculty of Engineering, Osaka Institute of Technology, 5-16-1 Omiya, Asahi-ku, Osaka 535-8585 Japan. email: yutaka.hiroi@oit.ac.jp

A. Ito is with Graduate School of Engineering, Tohoku University, 6-6-5 Aramaki aza Aoba, Aoba-ku, Sendai, 980-8579 Japan. e-mail: aito@spcom.ecei.tohoku.ac.jp

because of the inability to consider the sensory effect of a huge robot, such as the possible "sense of oppression." However, in this study, we chose this approach of varying the height of a small robot for two reasons. First, it is difficult in prcatice to conduct a perception experiment using robots of various heights, as robots of various sizes would first need to be manufactured. In addition, the operation of replacing the robot with which the participant of the experiment interacts during the experiment will affect the impression of the robots. Second, even if only the height of a same-sized robot is changed, the height is highly likely to affect any impression of the interaction. It is understood that in a dialog between humans using video images, the height at which the video equipment for the conversation is installed affects the content of the dialog [19].

The next issue is to decide the parameter that needs to be measured for assessing the effect of robot height on dialog. In this study, we decided to focus on a subjective evaluation of the impression of "comfortableness of interaction." It is possible to conduct long dialogs and measure the objective features of the conversation [19], but it is assumed that the majority of verbal interaction between humans and robots will be short, considering current voice recognition and spoken dialog technology. Thus we decided to conduct two-turn verbal interaction (in which the robot talks to the person and the person answers) and carry out a subjective evaluation of these dialogs.

In conclusion, the purpose of this study is to examine the effect of robot height on verbal interaction with a robot and to clarify the height at which the interaction is comfortable. We previously conducted an experiment for a similar purpose [17], but the research had several problems. In Section II, we briefly review an outline and problems of this research. In Section III, in order to achieve our goal, we first describe the development of a mechanism for changing the height of the robot. In Section IV describes the experiment. Finally, in Section V, we summarize our findings.

II. Our previous work and its problems

In [17] we developed a robot whose height can be changed [20], and conducted an experiment to investigate how the robot height affected the user's feeling when conversing with the robot. Figure 1 shows the robot used in the experiment, in which we evaluated the user's comfortableness of conversation with the robot using an automatic spoken dialog system.

However, we found four problems in the work. First, the range of height change was not enough to consider all of the effects caused by changing the robot's height. This problem was caused by the mechanism of the robot, which should be solved by changing the mechanism of height change. Second, we investigated the effect of a height change of only ±200mm. This small change was not enough to observe the impression of changes in height; we need to investigate the effect of a wider range of height change. Third, the experimental procedure had a problem. In the previous work, we first asked a participant to choose the "comfortable height" at which the participant felt most comfortable for conversation. However, the results of a subjective evaluation showed that in some cases the comfortable height is not really comfortable, because the height was chosen before the

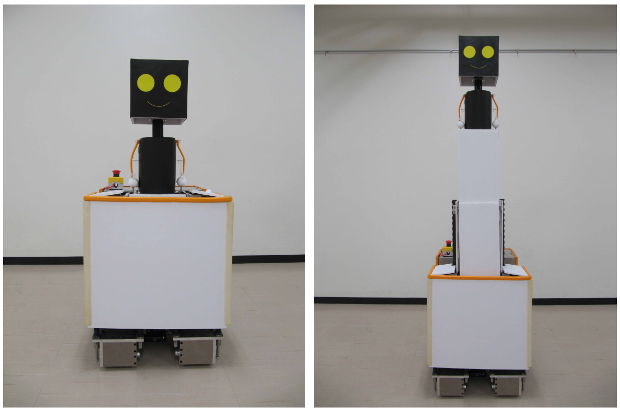


Fig. 1. Goyane, a robot with height change mechanism

user actually engaged in conversation. Fourth, in the previous work, the dialogs were conducted using an automatic spoken dialog system. However, to investigate the effect of robot height, we need to exclude the effect of the impression of the dialog system caused by the system's different replies.

To solve the four problems, we conducted new experiments with the following differences.

1) A new mechanism of height change is introduced to allow a wide range of height change.
2) We changed the robot height from the "comfortable height" to ± 100, 200 and 300mm to investigate the change of impression of the dialog in more detail.
3) We changed the procedure of the experiment for adjusting the robot to the "comfortable height" so that the evaluation score of that height becomes the maximum score. Moreover, we used the differential mean opinion score (DMOS) for the subjective evaluation to measure the reduction of comfortableness of interaction instead of measuring absolute comfortableness.
4) The new experiment was conducted on a Wizard-of-Oz basis [21] so that improper replies caused by misrecognition of speech did not occur.

In addition, we conducted an experiment on sitting posture to investigate the optimum height of the robot for dealing with seated persons. The next section gives an overview of the experiment.

III. Investigation of comfortable height for verbal interaction

A. A communication robot with height change mechanism

In this experiment, we first clarify a comfortable height of the robot for verbal interaction. Next, we adjust the height up and down from the "comfortable height" for interaction to determine when differences become apparent. We chose to investigate a range of comfortable height because a margin is needed when designing the height of a robot for practical use. Furthermore, we assumed two postures of the participants when in a dialog with a robot: standing or sitting, considering use of a robot in an office.

The experiment was conducted as follows. First, we asked the participants to stand in front of the robot and, after adjusting the robot to a height that the participant felt was "comfortable for verbal interaction," we asked them to engage in a short verbal interaction with the robot. Next, we changed the height of the robot from the comfortable height and asked them to interact with the robot again to evaluate whether the difference in height made them feel uncomfortable. We conducted the experiment from both a standing and a sitting position.

Existing communication robots have various heights, ranging from 400mm to around 1800mm [1]–[4]. Robots that have an adjustable height include the HSR developed by Toyota Motor Corporation, and the Cosero [22] developed by Bonn University. The height of the former can be adjusted by 500mm and the height of the latter by 900mm. These robots are able to grasp objects at various heights because their bodies, including the arms, are able to move up and down. Considering the purpose of our research, because the effect of a robot's height is unknown, it was necessary to use a mechanism that allowed a greater range of movement up and down and to examine the effect of height over a wider range. Accordingly, we developed a robot the height of which could be adjusted for this experiment.

The robot could be raised from the floor to a height 300mm higher than the average height of a male aged 18 to 29 (approximately 1714mm[1]). It was necessary to limit the effect of the height change mechanism on the impression formed by the participants during the experiment. Therefore, we designed a mechanism that moves up and down a pipe as shown in Fig. 2. For the experiment, the robot had to be able to move up and down stably to stop at arbitrary points. For example, if a wheel was used to move the robot vertically, the wheel would probably slip and the robot would rotate on the yaw axis while moving up and down. Therefore, we combined passive wheels and a rack-and-pinion gear to achieve vertical movement. Figure 3 (a) shows the height change mechanism mounted behind the robot; a rack gear is inserted in the groove in the pipe, which is meshed with a pinion gear to move up and down. We used a Dynamixel MX-28T[2] infinitely rotating servo as the actuator. The positional relationship of the wheel and pinion was set to approximately 120 degrees to prevent rotation toward the yaw axis. The drive wheels were installed at the top and bottom to eliminate the vibration of the body, as shown in Fig. 2. As shown in Fig. 4, the height change ranged from 45mm to 2019mm. The dimensions and weights of the height change mechanism and the mounted robot are shown in Table I. Furthermore, the neck of the communication robot was given a single degree of freedom to ensure that the robot faced the participant. We used RS405CB manufactured by Futaba for the actuator. We used two laptops in this experiment: one to control the communication robot and the other to control the height change mechanism and for audio output.

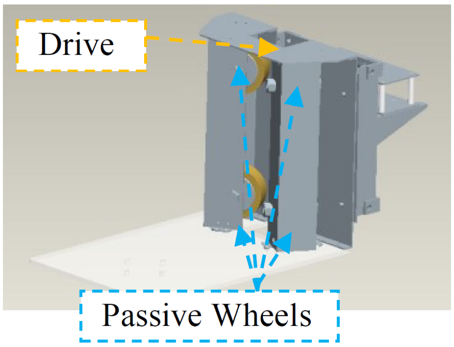
B. Design and overview of the experiment

The experiment was conducted in a 5000×8000mm room,, with no light penetrating from outside. Male undergraduate and graduate students aged 21 to 24 were given an explanation of the experiment, and 19 persons who consented to the experiment were employed as participants. In the experiment, the participant stood in front of the robot and the height of the robot, measured from the floor surface to the eyes of the robot, was adjusted. We changed the height of the robot, and stopped it at the height where the participant felt the interaction most comfortable (hereafter, "comfortable height"). Then we instructed the participant to verbally interact with the robot. Next, we asked the participant to evaluate the interaction according to a five-grade scale of 5: "Comfortable for interaction," 3: "Neither," and 1: "Not comfortable for interaction." This was repeated until the "comfortable height" was reached. In other words, the height of the robot was adjusted until the participant selected "5." Then we adjusted the height up and down from the comfortable height for dialog. We applied six conditions for the extent of change: ±(100mm, 200mm, 300mm). We evaluated for the extent of change by asking the participant to subjectively evaluate the difference between their impression of the dialog before the height change ("comfortable height") and their impression of the interaction after the height change.

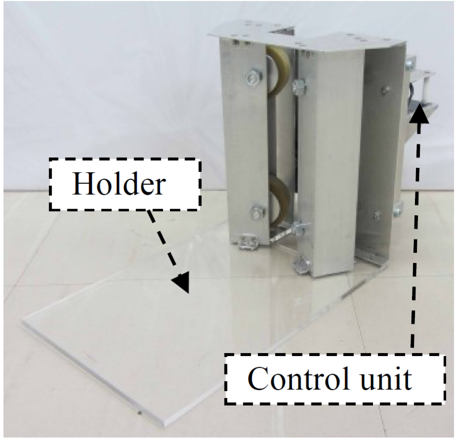
When designing the experiment, we needed to consider several issues, including: the distance between the participant

[1]AIST Human Body Dimension Database 1991-92, https://www.dh.aist.go.jp/database/91-92/main.html, (Reference date: 16/11/2013) (in Japanese)

[2]ROBOTIS Corporation, http://www.robotis.com/xe/, (Reference date: 01/27/2012)



(a) Height-change mechanism (3D model)



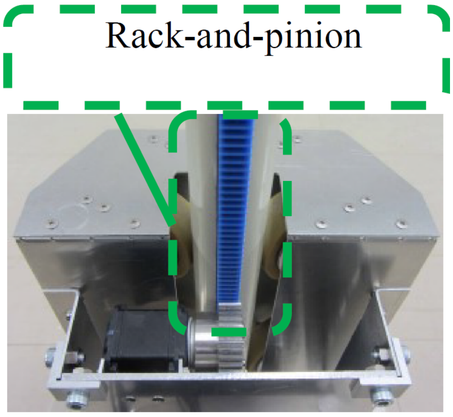
(b) Height-change mechanism (Product)

Fig. 2. The height change mechanism of the robot used in the experiment

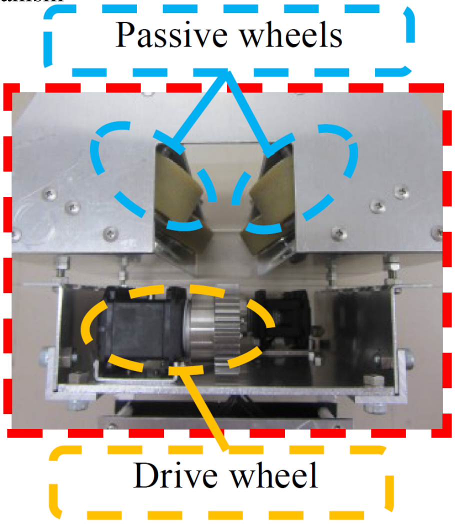
TABLE I
SPECIFICATION OF THE HEIGHT CHANGE MECHANISM

	Height change mechanism	Mounted robot
Dimensions(WDH) [mm]	$179 \times 403 \times 207$	$182 \times 182 \times 434$
Weight [g]	1929	821
Moving speed [mm/s]	35	-
Range of movement[mm]	1974	-

(a) Height change mechanism mounted on the communication robot



(b) Top view of the height change mechanism



(c) Magnified view of the drive unit

Fig. 3. The height change mechanism of the robot used in the experiment

and the robot, the robot's behavior during the interaction, the participant's posture, and how to conduct the interaction.

We positioned the robot 600mm from the participant, in view of the aim of developing a robot for practical use and in view of the accuracy of speech recognition [23]. Since the recognition accuracy drops severely when the speaker and the robot are more than 600mm apart, larger distance than this are impractical for verbal interaction. However, we also conducted the study at a distance of greater than 600mm to confirm the effect of distance on the comfortableness of interaction.

We controlled the robot to nod during the dialog to make the dialog feel more natural to the participants [14]. Furthermore, we controlled the robot such that it was always facing the participant in all experiments while changing the height. We also tested two postures of the participants: standing or sitting.

The experiment used the Wizard of Oz method [21] to eliminate the impact of misrecognition by the speech recognizer. With this method the operator operates the spoken dialog system by remote control and controls the interaction between the robot and participant. We used AquesTalk[3] as a speech synthesizer. The voice was emitted from a loudspeaker mounted on the back of the robot and the clarity of speech was verified for all experiments.

[3]AquesTalk a Text-to-Speech middleware, http://www.a-quest.com/products/aquestalk.html, (Reference date: 02/02/2012) (in Japanese)

C. Experimental environment and procedure

Next we describe the details of the experiment. We conducted the experiment in a 5000×8000mm room, shutting out any ambient light so as to eliminate its effects. The experiment was conducted on 19 male university and graduate students aged between 21 and 24. The experimental procedure was as follows.

1) Measure the height of the participant and the height from the floor surface to eye level before the experiment.
2) Using a jig, ask the participant to stand at 600mm from the robot (standing: Fig. 5 D1, sitting: Fig. 5 D2).
3) Hand the participant a headset and mouse and explain the operation method. Then, explain the content of the interaction.
4) Raise the communication robot from the floor surface and ask the participant to click the mouse at a height that is comfortable for interaction.
5) Check whether the height is appropriate, and if it is, initiate the interaction.

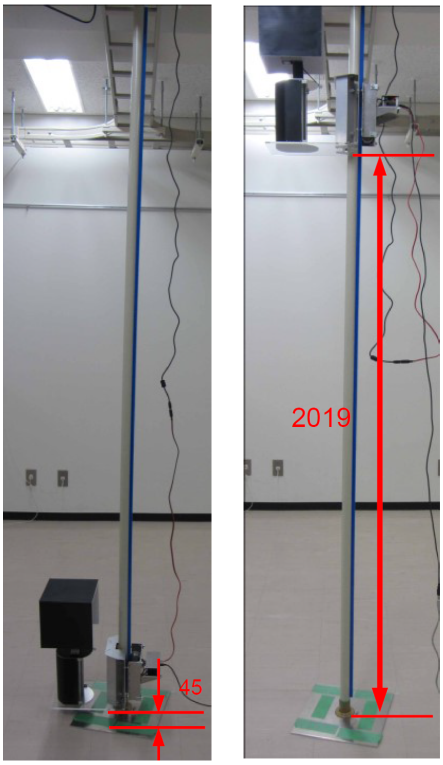


Fig. 4. Operating range of the height change mechanism [mm]

6) Ask the participant to fill out the survey.
7) Check the impression rating, and if “5” has been selected, go to step 12.
8) Ask the participant to state a preferred height.
9) Adjust the height in the specified direction and ask the participant to stop the robot in the same way as in step 4.
10) Initiate the interaction and fill out the survey.
11) Go to step 7.
12) Once the “comfortable height” evaluation is complete, adjust the robot height according to the six conditions (from −300mm to +300mm) and repeat the dialog and survey. The experimental conditions are randomly set for each participant.

We prepared the following short verbal interaction asking the participant’s gender.

Robot: “My name is Robot Avatar. Please tell me your gender.”
Experiment participant: “I’m a male/female.” “Male/female,” etc.
Robot: “I understand. Thank you.”

Next, we describe the evaluation of the participant’s impressions obtained by the a survey. As described above, the evaluation was based on a five-grade Likert scale. By adjusting the height, the evaluation at the comfortable height will always be “5. Comfortable for interaction.” For the evaluation after the height change, we conducted a relative evaluation against the comfortableness of interaction at the “comfortable height.” We referred to the Difference Mean Opinion Score (DMOS) evaluation for evaluating sound quality in speech and audio fields [24] and set the following evaluation criteria. Compared to the “comfortable height,” the participant is:

5: Not bothered at all by the difference in height.
4: Hardly bothered by the difference in height.
3: Slightly bothered by the difference in height.
2: Bothered by the difference in height.
1: Extremely bothered by the difference in height.

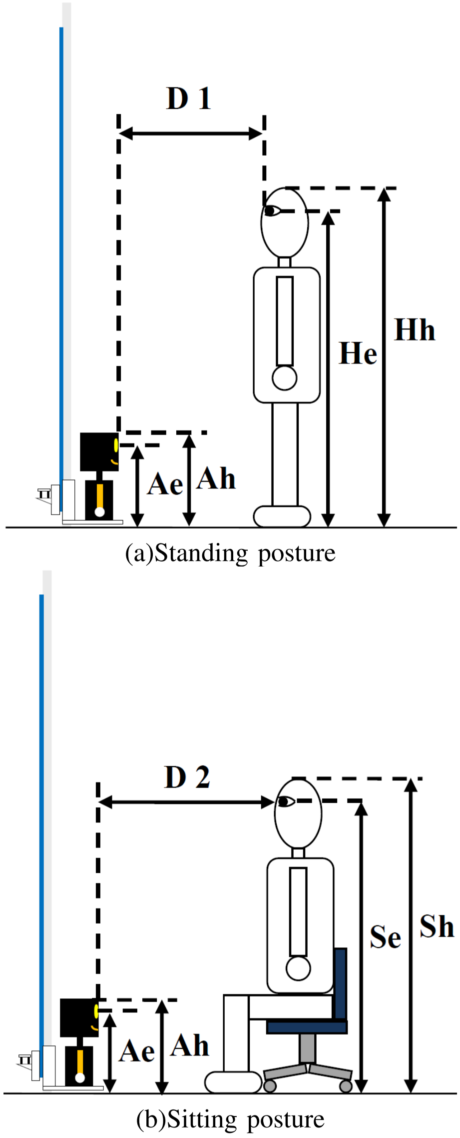


Fig. 5. Lengths in the experiment

A participant chose one score among the five grades for each robot height. After gathering scores of all conditions from all participants, the average score over all participants became the DMOS score of the condition. The aforementioned procedure was implemented for both the standing and sitting postures. The order of the standing posture and sitting posture were set up differently for each participant. The experimental parameters are shown in Fig. 5 and the layout of the experiment is depicted in Fig. 6.

D. Experimental results

1) Standing posture: Figure 7 shows the participant’s height, the height from the floor surface to the participant’s eye level, the “comfortable” height of the communication robot and the height from the floor surface to the robot’s eye level. The average values were: participant’s height (Hh): 1737mm, height from the floor surface to the participant’s

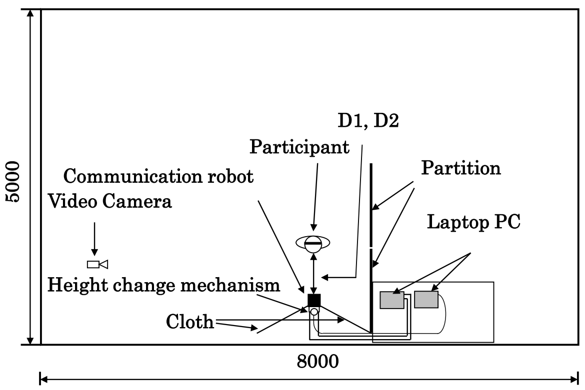


Fig. 6. Experimental environment

TABLE II
POPULATION OF SUBJECTS WITH POSITIVE AND NEGATIVE OPINIONS (STANDING POSTURE, $n = 19$)

	+300	+200	+100	−100	−200	−300
Pos.	6	9	15	10	3	1
Neg.	13	10	4	9	16	18

eye level (He): 1614mm, height of the communication robot (Ah): 1348mm, and height from the floor surface to the robot's eye level (Ae): 1274mm. When a t-test was conducted between Hh and Ah and He and Ae, a significant difference at the 1% significance level was found. Hence, it can be said that the robot height at which a participant feels the interaction to be comfortable is lower than human height and eye level height. This result is almost consistent with that obtained in the previous work [17], where Hh, He, Ah and Ae were 1733mm, 1616mm, 1346mm and 1276mm, respectively.

The results of the impression evaluation are shown in Fig. 8. The horizontal axis of the graph shows the experimental condition and the vertical axis shows the average evaluation score. Using the Bonferroni method for multiple comparison, we found a significant difference at the 1% significance level in the pairs $(+300, +200)$ and $(-100, -200)$, and at the 5% significance level in the pairs $(+200, +100)$ and $(+100, -100)$. There is a tendency for the participant to be increasingly bothered by the change in height the more the height is changed from the "comfortable" height. If we permit the height difference of "4: Hardly bothered by the difference in height", we can say that the height of the robot can be 100mm higher than the comfortable height. When actually designing a robot, there are many constraints including its height. If the criterion of comfortableness should be relaxed by other design factors, relaxing the difference to "3: Slightly bothered by the difference in height." could be another choice. In this case, the height can be 100mm lower or 200mm higher than the comfortable height. When the height becomes more than 100mm lower or 200mm higher, the interaction will become uncomfortable.

We categorized the comments in the comments section into positive and negative impressions (Table II). As with the impression results evaluation, the impressions of the dialog tended to be more negative for "−" conditions than for "+" conditions.

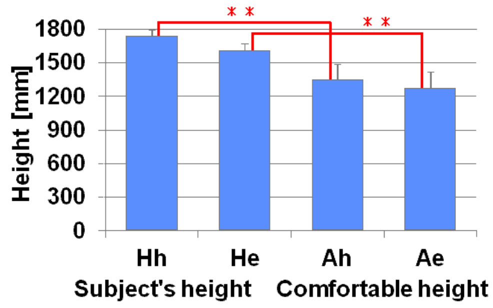


Fig. 7. Result of subject's height and comfortable height (standing posture, **: $p < 0.01, n = 19$)

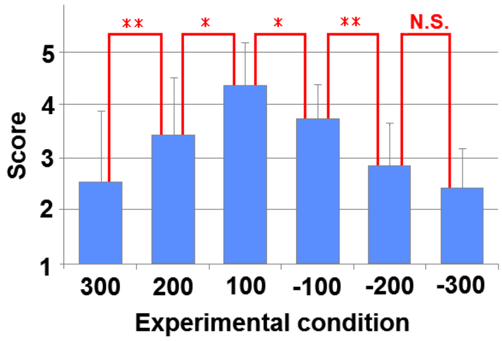


Fig. 8. Result of subject's height and comfortable height (standing posture, **: $p < 0.01, n = 19$)

2) Sitting posture: Figure 9 shows the averages of the four heights the same as in Fig. 7. The average values were: participant's height (Sh): 1272mm, height from the floor surface to the participant's eye level (Se): 1149mm, height of the communication robot (Ah): 932mm and height from the floor surface to the robot's eye level (Ae): 858mm. When a t-test was conducted between Sh and Ah and Se and Ae, a significant difference at the 1% significance level was found. Hence, it can be said that the robot height at which dialog feels comfortable is lower than human height and eye level height.

The results of the impression evaluation are shown in Fig. 10. The axes of the figure are the same as those of Fig. 8. Using the Bonferroni method for multiple comparison, we found a significant difference at the 1% significance level for the pairs $(+300, +200)$, $(+200, +100)$ and $(-100, -200)$. There is a tendency for the participant to be increasingly bothered by the change in height the more the height is changed from the "comfortable" height, as was the case with the standing posture.

We categorized the comments in the comments section into positive and negative impressions (Table III). As with the impression results evaluation, the impressions of the dialog tended to be more negative for "−" conditions than for "+" conditions.

E. Discussion

According to the experimental results, the height at which humans feel that dialog is comfortable in both postures was lower than human height or lower than human eye level. Specifically, the most comfortable height was when

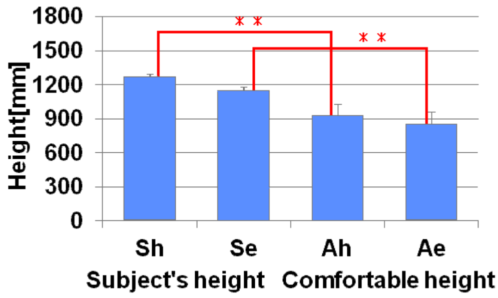


Fig. 9. Results of subject's height and comfortable height (sitting posture, **: $p < 0.01, n = 19$)

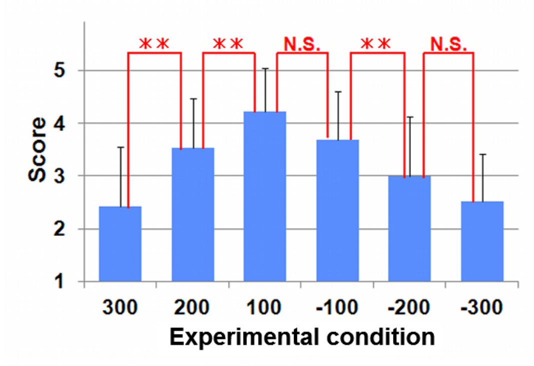


Fig. 10. Results of sitting posture (**: $p < 0.01$, *: $p < 0.05$, N.S.: not significant, $n = 19$)

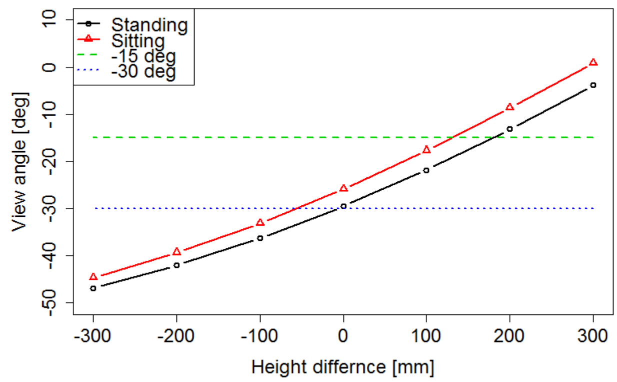


Fig. 11. Viewing angle of the user when looking at the robot's face

the robot's height from the floor surface was around 300mm lower than the human's height from the floor surface to eye level. In the standing posture, the "comfortable height" was 1348mm, which was similar to 1420mm, the preferred height in Lee et al. [13]. Lee et al. stated that this preference was related to ease of making eye contact, which also seems to be true for our results. This result also seems to be consistent with the knowledge of the optimum height of visual display for VDT work. From the discussion of Burgess-Limerick et al. [25], it is known that the optimum angle of the visual display is at least $-15°$ from the horizontal eye level, and other guidelines suggest that the optimum angle is between $-15°$ and $-30°$. The visual angle to the robot's face in the standing posture is $-29.5°$ and that in the sitting posture is $-25.9°$ when the robot's height is the comfortable height, which are similar to the recommended angle of display height. In addition, the viewing angle for various height changes is shown in Fig. 11. In this figure, the height change of 0mm shows the comfortable height, which is almost 300mm lower than the participant's eye level (depending on the posture of the participant). As shown in this figure, only the comfortable height (height difference = 0mm) and 100mm higher condition fit between $-15°$ and $-30°$, which could be one reason why only those two conditions showed a high subjective evaluation score (more than 4).

TABLE III
POPULATION OF SUBJECTS WITH POSITIVE AND NEGATIVE OPINIONS (SITTING POSTURE, $n = 19$)

	+300	+200	+100	-100	-200	-300
Pos.	3	7	17	14	5	2
Neg.	16	12	2	5	14	17

Comparing these results with the results obtained from the previous work [17], the basic results are consistent. In the previous work, we could only change the height of the robot by at most 200mm higher or lower than the comfortable height because of the restrictions of the hardware, and found that ease of dialog decreased when the change was 200mm higher or lower than the comfortable height. This consistency suggests that the result of the optimum height holds for robots with different shapes.

These results also suggest that the height of the height-change robot Goyane [17] can be changed to almost the "comfortable height" for both the standing and sitting postures. Strictly, in the sitting condition, Goyane's minimum height (1030mm) is slightly higher than the comfortable height (Ah = 932mm); although the 100mm difference does not adversely affect the comfortableness of dialog, a robot that needs to be developed that can acheve the best height for both the standing and sitting postures.

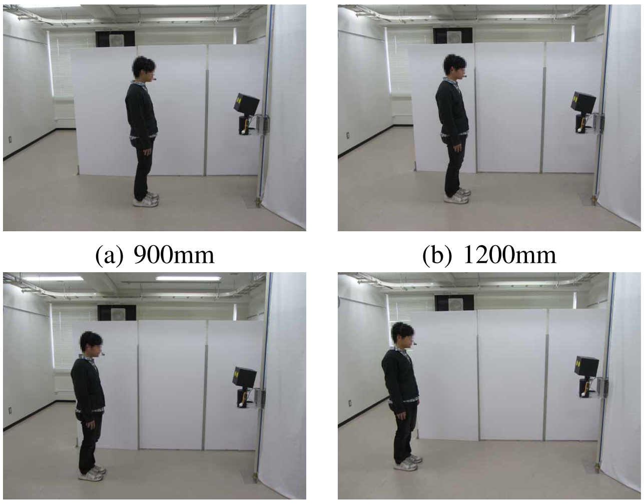
IV. Relationship between the comfortable height and human-robot distance

A. Setting up the experiment

We found that the height at which interaction is comfortable is lower than human height or the height from the floor surface to human eye level when the distance between a human and robot is 600mm,. If the comfortable height for dialog changes considerably when the distance is increased, it becomes necessary to adjust the height of the robot in accordance with the human to robot distance. Therefore, in this experiment, we added distance conditions (Fig. 5 D1:900, 1200, 1500 and 1800mm) and conducted an experiment for the comfortable height for interaction in Section III. We studied the effect that distance has on the comfortable height for interaction. In this experiment, we decided to conduct the experiment for the standing posture only, because the same tendencies were apparent for both tje standing and sitting postures in Section III.

B. Experiment environment and procedure

The experiment equipment, experiment location, dialog content, etc. were basically the same as those used in Section III The experiment was conducted on 19 male university and graduate students aged between 21 and 24, who cpnsented to the explanation of the experiment. Here, we only measured



(a) 900mm

(b) 1200mm

(c) 1500mm

(d) 1800mm

Fig. 12. Experimental conditions

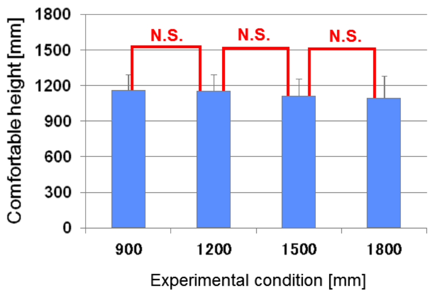


Fig. 13. Relationship between comfortable distance and human-robot distance (N.S.: not significant, $n = 19$)

the "comfortable height" and did not measure the effect of changing the robot's height. The experimental procedure was the same as that of Section III, except the human-robot distance (900, 1200, 1500 and 1800mm).

C. Experimental results

Figure 12 shows the participant and robot at each distance. The relationship between the human-robot distance and the comfortable height for dialog from floor surface to eye level is shown in Fig. 13. The horizontal axis represents the distance from the participant to the robot and the vertical axis represents the comfortable height for dialog from the floor surface to the eye level of the robot. When we conducted multiple comparisons using the Tukey method, no significant differences were found.

D. Discussion

It is suggested that even if the distance between the participant and robot increases, the comfortable height for dialog does not change. This result is considered to come from the fact that the height of the partner of the dialog does not change in accordance with a change in distance when conversing with a human. Therefore, it is not necessary to change the height of the robot regardless of the human-robot distance.

V. Conclusion

The purpose of this study was to examine the effect of robot height on verbal interaction and to clarify the height at which interaction is comfortable. Accordingly, we studied the optimum height for smooth human-robot communication. First, we clarified the comfortable height for verbal interaction and then studied what degree of vertical change from this height would be acceptable. Finally, we studied whether the comfortable height for interaction changed when the participant to robot distance was changed. We obtained the following results in this study.

1) The comfortable height is lower than human height or human eye level for both the standing and sitting postures. Specifically, the most comfortable height was when the robot's height from the floor surface was around 300mm lower than the human's height from the floor surface to eye level.
2) In the case of both postures, raising the robot 100mm does not adversely affect the comfortableness of interaction. If the robot is raised 300mm or lowered 200mm from the comfortable height for dialog, dialog becomes uncomfortable.
3) The comfortable height for dialog does not change even if the human to robot distance changes.

The above results clarify one point with regard to robot design height and verbal interaction. Since a human is able to tolerate a shorter robot when the robot is close to them [14], the ideal robot would be short when close to the human, but, taking into account the posture of the human, would increase in height during dialog as proposed by Hiroi et al [17]. In the future, we will conduct experiments in which we change the conditions according to age range (for example, a child's height is significantly different to the height of an adult) and gender, etc.

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