How Can Robot's Gaze Ratio and Body Direction Show an Awareness of Priority to the People with whom it is Interacting?

Honoka Arai, Mitsuhiko Kimoto, Takamasa Iio, Katsunori Shimohara, Reo Matsumura, and Masahiro Shiomi

***Abstract*—When a person interacts with others who require different levels of authority, her gaze ratio and body direction for each person are different, e.g., a salesperson who turns to and looks at a VIP more attentively than a member of that VIP's staff. In this study, we investigate the effects of gaze ratios and body directions with which social robots demonstrate an awareness of authority when they are simultaneously interacting with multiple persons. We develop a gaze-controller system for a social robot and experimentally investigate the effects of the gaze ratio and the body direction (*priority-oriented*: body direction turns to a target and *non-priority-oriented*: body direction does not turn to a target) when the robot salesperson is describing items to two persons who are playing different roles: a VIP and a follower (e.g., member of a VIP's staff). Our experiment results show that different advantages of gaze ratio and body direction demonstrate an awareness of priority. With the *priority-oriented* condition, participants more highly evaluated the gaze at a 100:0 ratio between VIPs and followers. But in the *non-priority-oriented* condition, the participants more highly evaluated the gaze ratios at 80:20 or 90:10. These results contribute to a gaze behavior design for social robots that interact with multiple persons who require different levels of priority.**

I. Introduction

In information-providing situations with multiple people, a speaker basically assigns similar gaze ratios to the addressees when their levels of authority are similar, and when they are different, the relationship is obviously also different. For example, when a salesperson is describing new products to an important customer and a member of that the customer's staff, she mainly looks at the valued customer during his explanation. Since such social gaze behaviors often occur in real settings, social robots also need to be equipped with an appropriate gaze-ratio control system when they act in such daily situations as museum guides [1-4], providing information to visitors or customers [5-10], and educational support for children [11-14].

Body direction also has essential roles during conversations. In the above situation where the salesperson interacts with the important customer and others, her body direction also turns to the customer. A past study investigated the effects of a virtual agent's body direction during an information-providing context and concluded that when the body direction was aligned toward its gaze direction, the perceived interest toward the contents improved [15]. Other studies focused on a robot's gaze ratio when the robot interacts with multiple persons, but less on its body direction effects. For instance, to maintain the O-space spatial relationship, past studies fixed the robot's body direction between the people and/or the objects [11, 16].

How do social robots assign gaze ratios to interact with multiple people with different authority levels and hence deserve different levels of respect? How does a robot's body direction influence the perceived impression to such multiple people? One simple answer is always turning and only looking at a person with more authority, but such an approach might be demeaning to another person with less prestige. If we can find an acceptable, balanced gaze ratio that influences the body direction for both people, the robot might achieve more natural and acceptable behaviors in such situations. Although several human-robot interaction studies modeled natural gaze behaviors [11, 16-19], they focused less on situations where a robot interacts with multiple people based on their priority relationships. We discussed the details in the next section.

Based on these contexts, we investigate the effects of gaze ratios and body direction when a robot simultaneously interacts with multiple persons to build into robots the ability to signal different levels of importance in conversations. First, we employ an information-providing situation with two persons: a VIP and a follower. We develop a gaze-controller system for a social robot with a depth sensor and answer the following two questions:

- What well-balanced gaze ratio is appropriate when a social robot interacts with people who have different levels of authority?

- How does the robot's body direction change the perceived impressions of the people who have different levels of authority? If so, what is a better combination between its body direction and gaze ratio?

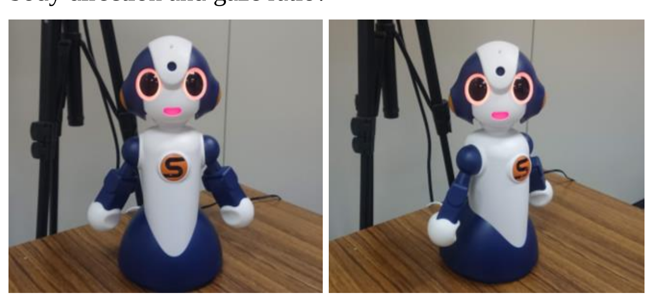

Figure 1. *Priority-oriented* (left) and *non- priority-oriented* (right) body direction during gazing behavior of a social robot

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H. Arai, M. Kimoto, T. Iio, K.Shimohara, Reo Matsumura, and Masahiro Shiomi are with ATR, Kyoto, Japan. (e-mail: m-shiomi@atr.jp).

H. Arai, M. Kimoto, and K. Shimohara are also with Doshisha Univ., Kyoto, Japan.

T. Iio is also with University of Tsukuba / JST PRESTO, Ibaraki, Japan.

Reo Matsumura is also with karakuri products Inc.

II. RELATED WORK

A. Gaze behavior design in human-robot interaction

Social gaze behavior is an active research topic in human-robot interaction. For instance, several researchers modeled a natural gaze control mechanism in human-robot interaction [11, 16-20]. Yamazaki et al. investigated the precise timing for controlling a robot's head (including gaze) and utterances for social robots [18]. Mutlu et al. pioneered modeling gaze behaviors for social robots in multi-party conversation settings, scrutinized human gaze behaviors, and implemented them in social robots [17, 19, 21]. Other researchers also developed mechanisms to control a social robot's gaze behaviors for multiple children based on Mutlu's work [11, 16]. Vázquez et al. investigated the effects of body orientation and gaze direction in group conversations between robots and people, but the robot's role was mainly as an addressee and priority relationships weren't considered [22]. From another perspective, Pejsa et al. investigated the effects of gaze and body direction and reported that affiliative gaze provides more positive perceived impressions such as likability and rapport than referential gaze [15].

These research works identified rich knowledge about modeling natural gaze behaviors for social robots and their effectiveness through various experiments on human-robot interaction. However, their interaction targets all have the same priorities. In other words, they focused less on gaze ratios and body direction effects for social robots when they interact with multiple persons who have different power relationships. One unique point of our study is its exploration of gaze behavior for a social robot by considering different priorities between interacting people.

B. Relationship effects in human-robot interaction

Typical human-robot interaction generally involves one-to-one interaction between a social robot and just one person. In such situations, robotics researchers usually assign lower authority to the robot than an interacting person, e.g., the robot always prioritizes the interaction person. For example, past studies developed a social coordination mechanism that prioritizes people for human-aware robot navigation and/or social coordination [23, 24].

Recently, due to installing social robots in actual environments, robots simultaneously need to interact with multiple persons. In such situations, they must consider the relationships among the interacting people to achieve more natural interactions. Researchers first focused on developing sensing systems that understand the relationships of people and used such information to decide a robot's behaviors. For instance, a robot approached parents to escape being bullied by children in a mall environment [25]. Another study estimated the social status of children by observing interactions with robots and children [26]. Oliveira et al. investigated people's non-verbal behaviors and socioemotional interactions toward robots with different relationships, such as partners or as opponents [27].

However, even if these studies enable social robots to interact with people by considering their relationships or recognizing them, they focused less on situations where a robot simultaneously interacts with multiple people who share different level of priorities. In other words, even if a robot recognizes the most important person in working contexts, appropriate behaviors and the effects of gaze ratio and body direction remain unknown. Therefore, we investigated the effects of gaze ratio and body direction to prioritize more powerful individuals.

III. EXPERIMENT DESIGN

In this section, we describe our robot and its sensors, the details of our gaze-control system, and its experimental settings. Fig. 2 shows an overview of our developed system that consists of the following components: a human-tracking system, a behavior controller, and a robot. The details of each component are described as follows.

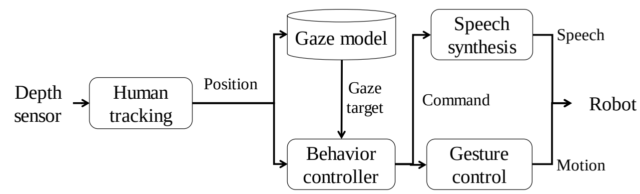

Figure 2. System overview

A. Human-tracking system

For multiple-person tracking, we used one depth sensor (Kinect V2) and a laptop PC to process the sensor data. The area for recognizing a person ranged from 0.5 to 4.5 m, the field's horizontal angle was 70°, and its perpendicular angle was 60°. This system sends the estimated head positions of the people using Kinect V2 libraries to the behavior selector through a wired network connection.

B. Robot

We used Sota, a desktop-sized interactive humanoid robot characterized by its humanlike physical expressions (Fig. 1). It has eight degrees of freedom (DOF): three in its head, two for its shoulders, one in each elbows, and another in its base. It is 28 cm tall with a voice synthesis function that can produce childlike and non-gendered sounds. The LED on its mouth blinks depending on the sound level to indicate speaking. Its gazes are autonomously controlled with a developed gaze model.

C. Gaze model

Although several gaze models have already been proposed in multi-party conversations [11, 17, 19], they mainly focused on situations where the interaction people share an identical power relationship. On the other hand, in this study the robot needs to appropriately assign the gaze ratio to show an awareness of the people's authority levels during information-providing. First, we developed a basic gaze control mechanism based on a previous study [17] whose mechanism focused on an information-providing situation where a robot interacts with two persons. That previous study only focused on using gaze behaviors, not body direction. In their model on average, the robot looked at the two addresses and its environment 35.5% and 29% of the time.

In our setting, the gaze targets are the two addresses and the environment. Based on a previously defined gaze-ratio probability [17], we set the initial gaze ratios to the targets to 35.0, 35.0, and 30.0% for an addressee, another addressee, and the environment. When the gaze target is the environment, the gaze angle was calculated from the points of the heads of the two participants. The robot's yaw was the center of the two participants, and the pitch was the center of the height of the two participants' heads minus 20 cm. We changed the gaze target every three seconds.

To investigate the gaze-ratio effects (Table I and Fig. 3), we fixed the gaze ratio to the environment (i.e., 30%) and only changed the balances for the addresses between 100:0 to 50:50. Thus, "100:0" indicates that the robot gazed at the VIP at 70%, the environment at 30%, and did not gaze at the follower. "50:50" indicates that the robot equally gazed at both the VIP and the follower at 35%, and the environment at 30%. We used slice resolutions as 10% ratio differences to comprehensively investigate the gaze-ratio effects, which we investigated with sliced resolutions, i.e., instead of gathering gaze-ratio data from human-human interaction settings, to avoid local minimum solutions about the gaze ratio.

During the *priority-oriented* body direction, the robot turned its face and base to the VIP when the gaze target was a VIP and only turned its face to the follower when the follower was the gaze target (Table II). During the *non-priority-oriented* body direction, the robot's base was fixed between the VIP and the follower and only turned its face to the gaze target (Table III).

IV. Experiment

A. Hypothesis and prediction

In human-human interaction, we implicitly change our behavior based on the authority relationships of those people with whom we are interacting. For example, a salesperson will probably turn to and look at a VIP more attentively than other customers. However, past human-robot interaction studies focused less on such priority relationships when a robot interacted with multiple people. By considering people's behaviors in such situations, we believe that gaze ratios and body direction can change the perceived impressions of people who have different authority levels and would outperform a commonly used gaze behavior for social robots. Based on these considerations, we made the following hypotheses:

Prediction 1: Specific combinations between biased gaze ratio and body direction will be evaluated more highly than traditional gaze behavior (i.e., 50:50 gaze ratio and *non-priority-oriented* body direction).

Due to the difficulties of complex combinations between all the gaze ratios and body directions, we cannot predict beforehand which combination is better between them. If our prediction is supported, we can identify better combinations that maximize user satisfaction by comparing the baseline group and other groups.

TABLE I. Gaze ratios for VIPs and followers

Gaze ratio	100:0	90:10	80:20	70:30	60:40	50:50
VIPs	70%	63%	56%	49%	42%	35%
Followers	0%	7%	14%	21%	28%	35%
Environment	30%	30%	30%	30%	30%	30%

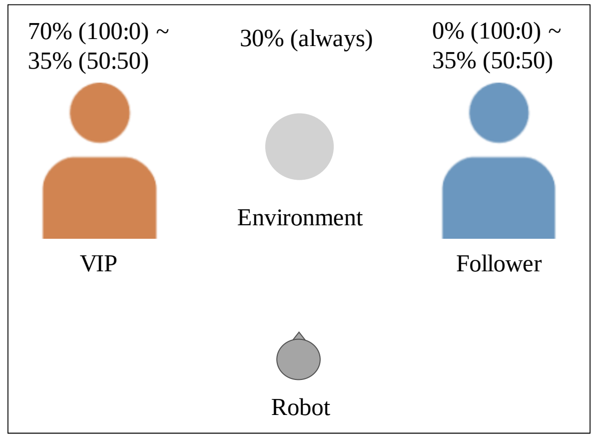

Figure 3. Illustration of gaze ratio for each target

TABLE II. Gaze behavior in *priority-oriented* condition

	Gaze target		
	VIP	Environment	Follower
VIP's viewpoint			
Follower's viewpoint			

TABLE III. Gaze behavior in *non-priority-oriented* condition

	Gaze target		
	VIP	Environment	Follower
VIP's viewpoint			
Follower's viewpoint			

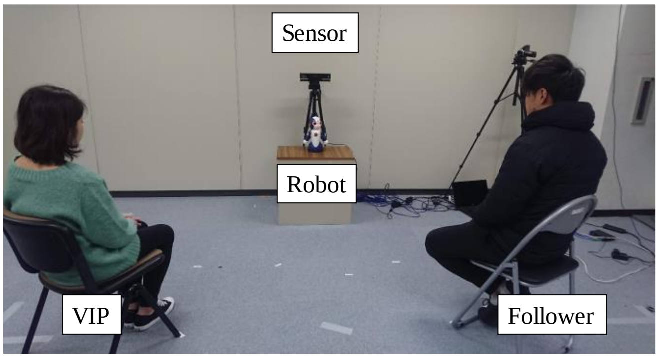

Figure 4. Experiment settings

B. Conditions

To verify our predictions, we conducted an exploratory experiment to investigate the effects of the gaze-ratio balances described in Section III.B as well as the body direction (*priority-oriented*/*non-priority-oriented*).

This study used a mixed factorial design that combined within- and between-participant designs. The number of within-participant factors was two: gaze-ratio and body-direction. The between-participant factor was the participant's roles: VIP and follower.

Gaze-ratio factor: This factor has six conditions. The robot changed the gaze ratios as described in Table 1.

Body-direction factor: This factor has two conditions. In the *priority-oriented* condition, the robot's body direction is fixed on the VIP, and the robot changes its face direction to look at the gaze target. In the *non-priority-oriented* condition, the robot's body direction is fixed toward the front (i.e., environment), and the robot only changes its face direction to look at the gaze target.

Role factor: This factor has two conditions: VIP and follower, both of which were assigned randomly. During the experiment, the participants did not change their roles.

C. Procedures

Before the experiment, the participants were given a brief description of the experiment procedure. In this study, we assigned different roles to each participant (VIP or follower) who worked together. Note that the assigned roles and their position information were manually inputted to the robot system to control the behaviors. Both participants listened to the robot and were told that the follower role has less authority than the VIP role. For instance, we told the participants to imagine several situations, such as a subordinate (follower) who is explaining her developed system to her superior (VIP) and where a follower guides a VIP at a shopping mall, and so on.

Participants joined 12 sessions. In each session, they listened to the robot's two-minute explanation about a smartphone. We prepared six conversation contents (e.g., the robot explains the item's name, its specs, and so on) and assigned them randomly during the 12 sessions. Note that we equaled the importance of each content and set similar lengths as much as possible because the importance of the contents influenced the timing of the gaze changes. After each session, both participants filled out questionnaires.

D. Participants

Twenty participants (ten females/ males, whose average ages were 30.25) participated in our experiment. They did not meet beforehand. All the trials included both genders. The numbers of VIP/follower roles were evenly distributed by gender.

E. Environment

Figure 4 shows an experiment scene where a robot provides information to two participants and looks at the follower. We prepared six kinds of two-minute contents about smartphones to reproduce a salesperson role for the robot. The participant playing the VIP sat in the left side chair in front of the robot, and the participant playing the follower sat on the right side.

F. Measurements

We measured four subjective items related to the perceived impressions by questionnaires to investigate the gaze-ratio and body-direction effects. The items were evaluated on a 1-to-7-point scale, where 1 is the most negative and 7 is the most positive.

- Intention to use (ITU) was three previously modified items [28]. The Cronbach alpha [29], which was 0.964 in this experiment, showed acceptable values for analysis.

- We defined two items for politeness: "The robot is polite" and "the robot is rude" (reversed item). The Cronbach alpha was 0.881.

- We defined two items for understandability: "this robot understood the power dynamic between the participants" and "this robot behaved based on an understanding of the power dynamic of the participants." The Cronbach alpha was 0.791.

- We defined one item for the total impression: "the total impression of the robot is good."

V. Results

A. Analysis of intention to use

Figure 5 shows the questionnaire results of intention to use. We conducted a three-factor mixed ANOVA for each scale on the gaze-ratio, body-direction, and role factors. The results (Table IV) showed a significant effect in the simple interaction effects between the gaze-ratio and body-direction factors ($F(5,90)=2.561$, $p=.033$, partial $\eta 2=.125$). We did not identify any significant main effects in the body-direction factor, the gaze-ratio factor, the role factor, the simple interaction effect between the body-direction and the role factors, the simple interaction effect between the gaze-ratio and the role factors, or the two-way interaction effects.

For a multiple comparison, we conducted a Dunnett's test to investigate what combinations between the gaze ratio and body direction outperformed the traditional gaze behavior (Section IV.A). For this purpose, we set the 50:50 gaze ratio and the *non-priority-oriented* body direction as the baseline and conducted a pairwise test with other combinations. As a result, four combinations were more highly evaluated (i.e., $p<.05$) than the baseline: 80:20, 90:10, and 100:0 with the *non-priority-oriented* body direction and 100:0 with the *priority-oriented* body direction.

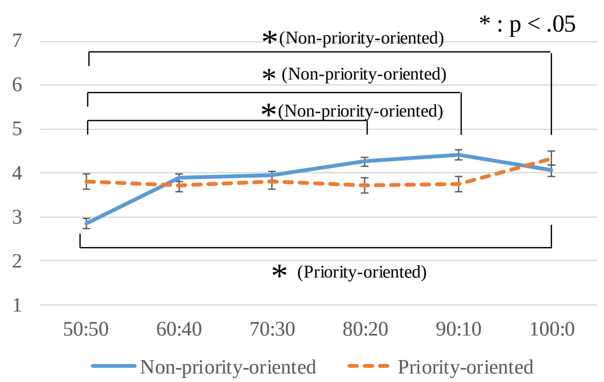

Figure 5. Questionnaire results of intention to use. Marks indicate significant differences compared to baseline (i.e., 50:50 gaze ratio and *non-priority-oriented* body direction).

TABLE IV. STATISTICAL RESULTS OF INTENTION TO USE (BOLD INDICATES THAT P-VALUE IS LESS THAN .05)

Source	F	*p*	Partial η2
Body direction (B)	0.033	0.857	0.002
Gaze (G)	1.959	0.092	0.098
Role (R)	3.422	0.081	0.160
B * R	0.072	0.791	0.004
G * R	0.495	0.779	0.027
B * G	**2.561**	**0.033**	**0.125**
B * G * R	0.253	0.937	0.014

B. *Analysis of politeness*

Figure 6 shows the politeness results of understandability. We conducted a three-factor mixed ANOVA for each scale on gaze-ratio, body-direction, and role factors. The results (Table V) showed a significant effect in the simple interaction effects between the body-direction and gaze-ratio factors (F(1,18)=3.797, *p*=.004, partial η2=.174). We did not identify any significant main effects in the body-direction factor, the gaze-ratio factor, the role factor, the simple interaction effect between the body-direction and the role factors, the simple interaction effect between the gaze-ratio and the role factors, or the two-way interaction effects.

For a multiple comparison, we also conducted a Dunnett's test for the pairwise test between the baseline and other combinations. Three combinations were more highly evaluated (i.e., *p*<.05) than the baseline: 70:30, 80:20, and 90:10 with a *non-priority-oriented* body direction.

C. *Analysis of understandability*

Figure 7 shows the questionnaire results of understandability. We conducted a three-factor mixed ANOVA for each scale on the gaze-ratio, body-direction, and role factors. The results (Table VI) showed significant main effects in the gaze-ratio factor (F(1,18)=12.483, *p*=.001, partial η2=.410) and simple interaction effects between the body-direction and gaze-ratio factors (F(1,18)=4.749, *p*=.001, partial η2=.209). We did not identify any significant effects in the body-direction factor, the role factor, the simple interaction effect between the body-direction and the role factors, the simple interaction effect between the gaze-ratio and the role factors, or the two-way interaction effects.

For a multiple comparison, we also conducted a Dunnett's test for a pairwise test between the baseline and other combinations. Ten combinations were more highly evaluated (i.e., *p*<.05) than the baseline: 70:30, 80:20, 90:10, and 100:0 with the *non-priority-oriented* body direction, and all the gaze ratios with the *priority-oriented* body direction. Therefore, we only showed the non-significant combination (60:40 gaze ratio and non-priority-oriented body direction) in the Fig.7 for readability.

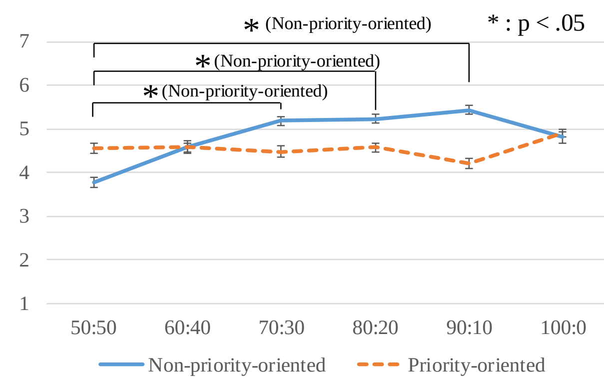

Figure 6. Questionnaire results of politeness. Marks indicate significant differences compared to baseline (i.e., 50:50 gaze ratio and *non-priority-oriented* body direction).

TABLE V. STATISTICAL RESULTS OF POLITENESS (BOLD INDICATES THAT P-VALUE IS LESS THAN .05)

Source	F	*p*	Partial η2
Body direction (B)	1.913	0.184	0.096
Gaze (G)	1.151	0.339	0.060
Role (R)	0.043	0.838	0.002
B * R	0.478	0.498	0.026
G * R	0.784	0.564	0.042
B * G	**3.797**	**0.004**	**0.174**
B * G * R	2.201	0.061	0.109

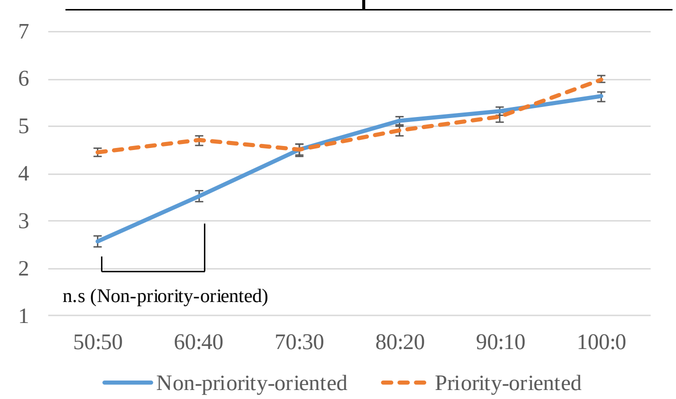

Figure 7. Questionnaire results of understandability. Except for "n.s" mark (60:40 gaze ratio and non-priority-oriented body direction), all comparisons with baseline showed significant differences.

TABLE VI. STATISTICAL RESULTS OF UNDERSTANDABILITY
(BOLD INDICATES P-VALUE IS LESS THAN .05)

Source	F	*p*	Partial η2
Body direction (B)	3.508	0.077	0.163
Gaze (G)	**12.483**	**0.001**	**0.410**
Role (R)	0.743	0.400	0.040
B * R	0.284	0.601	0.016
G * R	1.396	0.253	0.072
B * G	**20.243**	**0.001**	**0.529**
B * G * R	1.914	0.183	0.096

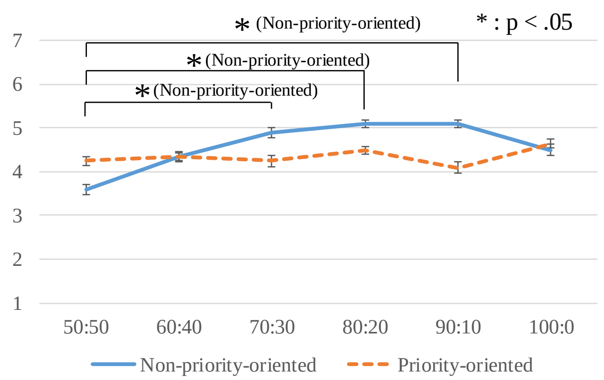

Figure 8. Questionnaire results of total impression. Marks indicate significant differences compared to baseline (i.e., 50:50 gaze ratio and *non-priority-oriented* body direction)

TABLE VII. STATISTICAL RESULTS OF TOTAL IMPRESSIONS
(BOLD INDICATES P-VALUE IS LESS THAN .05)

Source	F	*p*	Partial η2
Body direction (B)	1.176	0.293	0.061
Gaze (G)	1.496	0.199	0.077
Role (R)	0.405	0.533	0.022
B * R	0.035	0.854	0.002
G * R	0.445	0.816	0.024
B * G	**2.615**	**0.030**	**0.127**
B * G * R	0.734	0.600	0.039

D. Analysis of total impressions

Figure 8 shows the questionnaire results of the total impressions. We conducted a three-factor mixed ANOVA for each scale on the gaze-ratio, body-direction, and role factors. The results (Table VII) showed simple interaction effects between the body-direction and gaze-ratio factors ($F(1,18)=2.615$, $p=.030$, partial η2=.137). We did not identify any significant main effects in the body-direction, gaze-ratio, and the role factors or in the simple interaction effects between the body-direction and role factors, between the gaze-ratio and role factors, or between the two-way interaction effects.

For a multiple comparison, we also conducted a Dunnett's test for the pairwise test between the baseline and other combinations. Three combinations were more highly evaluated (i.e., $p<.05$) than the baseline: 70:30, 80:20, and 90:10 with the *non-priority-oriented* body direction.

E. Summary of analysis

By considering the statistical analysis results, prediction 1 was supported. We found several combinations between the biased gaze ratio and the body direction that are more highly evaluated than the baseline. We also found that the better gaze ratios are different based on body directions. In the *non-priority-oriented* body direction, 80:20 or 90:10 gaze ratios maximized participant satisfaction because they are significantly better than the baseline in all the measurements. In the *priority-oriented* body direction, the 100:0 gaze ratio maximized participant satisfaction in some of the measurements. Note that all the gaze ratios with the *priority-oriented* body direction were better from the viewpoint of understandability. If a robot needs to keep a non-biased gaze ratio (i.e., 50:50), a *priority-oriented* body direction remains useful to imply its capability to people who have different authority. We found no significant differences in the role factor.

VI. DISCUSSION

A. Design implications and contribution to HRI

One important contribution of this paper is that we identified the importance of the biased gaze ratio for social robots that must consider different power levels for the people with whom they are interacting. Since past studies basically assumed that interacting people have identical status, the existing gaze models assign similar gaze ratios to social robots. However, situations where robots need to interact with multiple people with different levels of authority must be considered in daily environments. Our results show that a balanced gaze ratio (50:50) in such situations create relatively negative impressions in people.

Based on these results, we discuss two guidelines and the design implications for the gaze behaviors of social robots to show an awareness of authority. First, if a developer uses a robot with the capability to change both its face and body direction (like Pepper, Nao, and Sota), its gaze behaviors can be controlled for information-providing tasks in two ways: *non-priority-oriented* body direction or *priority-oriented* body direction with biased gaze ratios. Although our study did not find any significant differences between them, it did identify advantages for the *non-priority-oriented* body direction with a balanced gaze ratio, which is the traditional way of information-providing for social robots.

Second, if a developer uses robots with relatively simple mechanisms that can only change their face direction (like PaPeRo I or static robots that use displays to show their eyes), i.e., can only use the *non-priority-oriented* body direction, a biased gaze ratio with 80:20 or 90:10 ratio is more suitable. In other words, our study also suggests that only changing the gaze ratio can exhibit an awareness of authority, and this knowledge is useful for such robots.

From another perspective, if a robot needs to show such awareness of priority, it should consider its own available modalities in interaction. In this study, the robot uses such different modalities as gaze direction and body direction. Our results suggest that a biased ratio of either modality is useful for such purposes, i.e., participants more highly evaluated a *priority-oriented* body direction with a 50:50 gaze ratio (i.e., only its body direction is biased) and a 100:0 gaze ratio (both the gaze ratio and body direction are biased), or a *non-priority-oriented* body direction with a 80:20/90:10 ratio (only the gaze ratio is biased). Based on these considerations, if a developer uses a robot that can only change its body direction (like Keepon), i.e., can only use a *priority-oriented* body direction, a biased gaze ratio of 80:20/90:10 is probably more suitable because such a robot can only use its body direction as a modality. Our results suggest that completely ignoring a follower might offend, as discussed above.

B. Gaze behavior design with more interacting people

In this study, we only focused on a situation with two people. If a robot interacts with more people, what kinds of gaze ratios and behaviors are appropriate? When the number of VIPs/followers increases, we thought that simply separating the gaze ratios based on their number is inappropriate. We suggested assigning a 80/90% ratio to the most important target and spreading the remaining 20/10% among the other targets. During a lecture, the robot should sweep its gaze over all the audience members and make eye contact with VIPs.

Moreover, in such situations, accurate human-tracking systems and person identification functions are needed. In this study we manually assigned role information to the robot system, but such recent image recognition functions as face identification are useful for autonomous systems that identify VIPs/followers from among interacting people. Several past studies also used environmental sensor systems to simultaneously track and identify multiple people [26, 30]. Such knowledge is critical for interacting with multiple people based on priority relationships.

C. Different modalities to show awareness

In this study, we focused on gaze ratios and behaviors to show an awareness of power relationships, but of course the robot can use other modalities for this purpose. For example, if it uses respectful language and/or gestures during interaction with a specific interacting person, such behavior conveys an awareness of authority. Combinations of appropriate gaze behaviors and such different modalities are also useful; as discussed above, some different modalities should be used with a biased ratio to show such awareness.

On the other hand, if a robot's gaze behavior and other modalities are mismatched, i.e., if a robot uses respectful language but a smaller gaze ratio, people might infer awkward impressions. We did not investigate different levels of power relationships. If a robot interacts with a person whose status is much higher, such as a member of a royal family, the robot must show such awareness using all of its modalities.

TABLE VIII. CORRELATION AMONG QUESTIONNAIRE ITEMS. * SIGNIFICANT CORRELATION AT 0.005 LEVEL (2-TAILED)

	1	2	3	4
1. Intention to use	-	-	-	-
2. Politeness	0.684*	-	-	-
3. Understandability	0.573*	0.598*	-	-
4. Total impression	0.797*	0.856*	0.645*	-

D. Factor analysis among measurements

In this study, three measurements (i.e., intention to use, politeness, and total impression) show similar patterns based on gaze ratios and body directions. Our correlation analysis showed that all items are strongly correlated with significant levels (Table VIII). Therefore, we conducted a factor analysis to investigate the relationships among the measurements. It yielded two factors that explain 68.4% of the variance for the entire set of variables. This first factor, hereinafter "perceived usability", which consists of intention to use, politeness, and total impressions, explained 59.95% of the variance, and the second factor (understandability) explained 8.53% of it. These results suggest that the understandability did not directly influence the perceived usability (i.e., intention to use, politeness, and total impressions).

E. Limitation and future work

Since we only used an existing robot (Sota), generality about robot appearance is limited. To use our knowledge in actual environments, we need to investigate whether different kinds of robots show an awareness of power relationships using biased gaze ratios and body directions.

We experimented with a pair of participants with a representative of each gender, i.e., only cross-gender settings. Therefore, investigating critical mixed gender effects while analyzing gazing behaviors would provide richer knowledge. In addition, such other factors as age and appearance effects are important.

In this study, the robot's body direction always faced the VIPs as *priority-oriented* body direction settings, but the experiment did not cover the effects of mixed gaze behavior between the *non-priority-oriented* and *priority-oriented* body directions.

Another future work will investigate the relationships between the importance of the conversation contents and the timing of gaze changes. For example, a salesperson will look at and turn to a VIP person when she explains a critical piece of information. Although we leveled the importance of the explained contents with similar lengths to avoid this difficulty, it would be another interesting future work.

VII. CONCLUSION

During interactions with people who have different levels of authority, gaze ratios and body-directions are useful to convey an awareness of such social power dynamics. In this study we investigated which gaze ratios between VIPs and followers and which body direction (i.e., *priority-oriented* or *non-priority-oriented*) are conducive for social robots that are interacting with people of different power relationships in an information-providing task. We developed a gaze control mechanism for a social robot and conducted experiments.

Our experiment results showed that a biased gaze ratio and body direction while gazing are crucial to exhibit an awareness of authority and the perceived impressions of the robot from the participants. Our results suggest that if the robot uses a *non-priority-oriented* body direction, biased gaze ratios (80:20/90:10) will be more positively inferred by the people. If the robot uses a *priority-oriented* body direction, a completely biased gaze ratio (100:0) will be positively perceived; a balanced gaze ratio (50:50) also has an advantage to convey its capability to people who have different levels of authority. These experiment results provide knowledge about future gaze behavior design for social robots.

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