

Who Should Speak? Voice Cue Design for a Mobile Robot Riding in a Smart Elevator

Masahiro Shiomi, Masayuki Kakio, and Takahiro Miyashita

Abstract—Recent mobile robots have the capability to take elevators from different floors in buildings. Although various technologies enable robots to use elevators for their daily environments, past research works mainly focused on the side of mobile robots, e.g., social behaviors through the robot’s device. In other words, the effects of social behaviors from smart elevators and the collaborative situations between mobile robots and elevators have received inadequate attention. Therefore, in this study, we investigate the effects of interaction design for a mobile robot and a smart elevator when the former takes the latter. We conducted an experiment where a mobile robot and/or an elevator spoke to passengers as voice cues and evaluated their perceived impressions toward the robot and the elevator. The experiment results showed positive effects of the voice cues of the smart elevator and the mobile robot, although we found no combination effects of both voice cues. On the other hand, either voice cue creates a positive impression toward the other, i.e., the elevator voice cue improves the perceived impressions of the mobile robot and vice versa. This phenomenon provides useful knowledge for both elevator/robot developers.

I. INTRODUCTION

Recent mobile robots have the capability to take elevators and move around in buildings [1-4]. For example, researchers developed mobile robots that have arms to control elevators by operation panels [5-7]. Related to this approach, several studies recognized operation panels using vision information [8-10]. Another approach is to upgrade elevators to enable communication between elevators and mobile robots [11-13]. These studies identified useful approaches to enable robots to take elevators for their daily movement requirements.

Some studies focused on the social behavior of mobile robots when they are waiting for the elevator with people or when they are actually riding in one. For example, a past study investigated human-like touchpoint behaviors, such as indicating a robot’s status by LED lighting and sound cues, in a situation where a robot enters an elevator [14]. Another study also used visual and audio cues to solve conflicts with people in an elevator [15]. A past study investigated by online surveys the preferred standing positions of both a mobile robot and a person in an elevator [16], and another compared machine-like or human-like waiting behaviors in a real environment [17]. Thus, these studies provided knowledge for social robots to use elevators with socially acceptable behaviors.

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However, although these technologies enable robots to use elevators in their daily environments, these studies focused on only the mobile robots’ side, e.g., social behaviors from the perspective of the robot’s device. In other words, so far research has basically neglected the effects of such social behaviors as voice cues that convey information from smart elevators, which can interact with visitors and other external systems, and the collaborative situations between mobile robots and elevators. Since some future mobile robots will undoubtedly be without the ability to express voice cues while taking elevators, investigating the effectiveness of voice cues from elevators will provide useful insights into the social behavior design for such robots. In addition, if collaboration between elevators and mobile robots increases the acceptability of voice cues, such a situation will also provide valuable insights.

Therefore, in this study, we investigated the effects of voice cue design for a mobile robot and a smart elevator when the former takes the latter (Fig.1). For this purpose, we developed a teleoperated mobile robot and a smart elevator, both of which have the capability to speak to passengers.



Figure 1. A mobile robot takes a smart elevator

II. RELATED WORK

A. Robot-elevator interaction

Robotics researchers have developed several mobile robots that can physically and non-physically interact with elevators. The former studies focused on two functions: visually detecting the elevator’s operation panels [5-7] and pressing the buttons using their arms [8-10]. Researchers of these studies successfully developed and evaluated functions that achieved human-like elevator control methods (i.e., finding panels and pressing buttons).

The latter studies focused on communication methods between mobile robots and smart elevators and advanced

capabilities to connect other systems via networks [11-13]. Some studies developed voice interaction capabilities for smart elevators [16, 17]; such trials enable robots to control the elevators by voice commands. These studies mainly integrated mobile robots and elevator control systems to enable robots to move around multiple floors by autonomously using elevators.

From another perspective, a few studies described the importance of social behaviors toward passengers when a robot uses elevators, such as visual/voice cues [12, 13] and waiting/standing positions [16, 17]. These studies focused on human-robot interaction situations around elevators, although these perspectives are also critical to designing social-robot-elevator interactions.

Thus, past studies reported how to create smooth robot-elevator interaction and emphasized the importance of social behaviors when mobile robots take elevators. On the other hand, the effects of such social behaviors as voice cues from elevators and the combined effects of both mobile robots and elevators have not yet been well investigated.

B. Voice interaction with multiple robots

In this study, we treat an elevator as a robot and investigate the effectiveness of its speaker role and voice interaction effects between the elevator and a mobile robot. From this perspective, past studies, which focused on voice interaction with multiple robots, provide useful knowledge for our study.

Researchers have broadly investigated the effects of using multiple robots [18, 19]. Many of these studies reported how effectively multiple robots performed the following functions: information-providing tasks [20-22], education and motivation improvements [23-25], persuasion [26-28], apology behaviors [29], recommendations [30-32], comedy performances [33, 34], expressing cute feelings [35], etc. These past studies showed the effectiveness of using multiple robots in various tasks and categorized interaction styles based on multiple robots.

Unfortunately, these studies focused on conversational settings, disregarding situations where mobile robots take elevators and without investigating the perceived impressions of passengers toward collaboration between mobile robots and elevators.

III. EXPERIMENT

A. Hypothesis and prediction

Past studies reported that the social behaviors of mobile robots, such as voice cues, are useful for achieving acceptable interaction with passengers when the robots take elevators [14, 15]. Recent smart elevators have capabilities that allow interaction with passengers [36, 37], although past studies failed to adequately focus on social behaviors like voice cues from elevators as well as collaborating interaction between elevators and robots. However, other previous research described the effectiveness of using multiple robots in conversational interactions [20-22]. Since the interaction effects between elevators and robots remain inadequately investigated, we hypothesized that such interaction might positively affect passengers. Following this hypothesis, we prepared the following prediction.

Prediction 1: Participants will have more positive impressions of the mobile robot when it uses voice cues than when it does not exhibit them.

Prediction 2: Participants will have more positive impressions of the elevator when it uses voice cues than when it does not exhibit them.

Prediction 3: Participants will have more positive impressions toward the elevator and the robot when both use voice cues than when just either the elevator or the robot uses them.

B. Participants

Thirty people participated in our experiment: 15 women and 15 men. Their ages ranged from 20s to 50s, and their average age was 39.4 (S. D. = 11.6). They applied through a temporary employment agency.

B. Environment

Figure 2 shows the experimental environment. We conducted it with a mobile robot (Fig. 3, left) at our laboratory and used an elevator in it (Fig. 3, right). The details of the robot are described in Section III-C. The elevator has operation panels on both sides of the door (Fig. 1). The size of the elevator is 2.3 m high, 1.35 m wide, and 1.6 m deep. For safety concerns, the robot was controlled from an operational space, which was enclosed by partitions. We installed a network camera inside the elevator for teleoperation control.

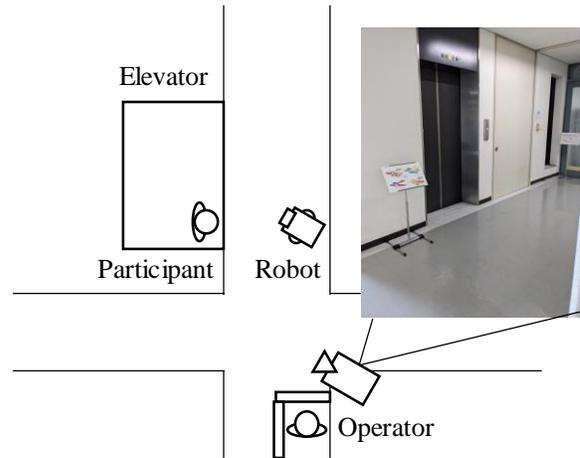


Figure 2. Experimental environment



Figure 3. The mobile robot and inside the elevator

C. Robots and teleoperation system

We used a 1420-mm-tall, 500-mm-wide, and 630-mm-deep mobile robot with a shelf on a mobile base. Its maximum locomotion speed is 160 mm/s when riding in the elevator. The robot's display has two eyes that resemble a face and is equipped a speaker on the head of the shelf.

We employed a wizard-of-oz (WoZ) approach [38] and prepared a teleoperation system for the mobile robot. The operator controls the locomotion speed, the robot's speech function (VOICEVOX, KotoyomiNia), and the elevator's speech function (VOICEVOX, NekotukaR).

D. Condition

We prepared four conditions, (Fig. 4). We prepared two factors: an *elevator* factor (didn't speak/spoke) and a *robot* factor (didn't speak/spoke). "The robot will now take the elevator" and "Please wait a moment" are its spoken contents. The speech is timed for when the robot approaches the elevator.

Except for condition 1 (i.e., neither the elevator nor the robot speaks), we unified the information amount. Therefore, in conditions 2 and 3, the elevator or the robot said two sentences. In condition 4, the elevator and the robot said one sentence each. We fixed the order of the speakers due to the speaker's content; the elevator speaks first, followed by the robot.

	Elevator (didn't speak)	Elevator (spoke)
Robot (didn't speak)	 ①	 ②
Robot (spoke)	 ③	 ④

Figure 4. Illustration of experiment conditions



Figure 5. The robot takes the elevator while the participant is waiting in it

E. Measurements

In this study, we evaluated the perceived impressions of the elevator and the robot with existing questionnaire scales: likeability [39], perceived intelligence [39], and safety [39]. The items were assessed on a 1-to-7 response format, where 1 denoted the most negative answer and 7 the most positive.

F. Procedure

All the procedures were approved by the Advanced Telecommunication Research Review Boards (525). First, the participants read explanations about the experiment and how to evaluate the robot and the elevator in each condition. We employed a within-participant design where the participants experienced four different conditions. After starting the experiment, the participants first took the elevator, followed by the robot (Fig. 5, left). Due to this condition, the robot and/or the elevator spoke for the timing of the robot approaching the elevator. The robot stood near the operation panel on the opposite side of the participants' standing point. After the robot rode the elevator (Fig. 5, right), the participants answered questionnaires. The order of the conditions was counterbalanced.

IV. RESULTS

A. Questionnaire results

We conducted a two-factor (*elevator* and *robot*) ANOVA to analyze the questionnaire results (Figs. 6-11). The analysis of the elevator's likeability scale showed a significant difference in the *elevator* factor ($F(1, 29) = 10.768, p = 0.003, \text{partial } \eta^2 = 0.271$), in the *robot* factor ($F(1, 29) = 5.751, p = 0.023, \text{partial } \eta^2 = 0.165$), and in the interaction effects ($F(1, 29) = 19.845, p < 0.001, \text{partial } \eta^2 = 0.406$). The simple main effects showed significant differences: *robot-didn't-speak* < *robot-spoke* in the *elevator-didn't-speak* condition ($p < 0.001$) and *elevator-didn't-speak* < *elevator-spoke* in the *robot-didn't-speak* condition ($p < 0.001$).

The analysis of the elevator's intelligence scale showed a significant difference in the *elevator* factor ($F(1, 29) = 32.235, p < 0.001, \text{partial } \eta^2 = 0.526$) and in the interaction effects ($F(1, 29) = 16.230, p < 0.001, \text{partial } \eta^2 = 0.359$). The results did not show significant differences in the *robot* factor ($F(1, 29) = 1.670, p = 0.206, \text{partial } \eta^2 = 0.054$). The simple main effects showed significant differences: *robot-didn't-speak* < *robot-spoke* in the *elevator-didn't-speak* condition ($p = 0.004$).

and *elevator-didn't-speak* < *elevator-spoke* in the *robot-didn't-speak* condition ($p < 0.001$).

The analysis of the elevator's safety scale showed a significant difference in the interaction effects ($F(1, 29) = 5.351, p = 0.028, \text{partial } \eta^2 = 0.156$). The results did not show significant differences in the *elevator* factor ($F(1, 29) = 3.061, p = 0.091, \text{partial } \eta^2 = 0.095$) or in the *robot* factor ($F(1, 29) = 0.364, p = 0.551, \text{partial } \eta^2 = 0.012$). The simple main effects showed significant differences: *elevator-didn't-speak* < *elevator-spoke* in the *robot-didn't-speak* condition ($p = 0.007$).

The analysis of the robot's likeability scale showed a significant difference in the *robot* factor ($F(1, 29) = 46.991, p < 0.001, \text{partial } \eta^2 = 0.618$) and in the interaction effects ($F(1, 29) = 32.977, p < 0.001, \text{partial } \eta^2 = 0.532$). The results did not show significant differences in the *elevator* factor ($F(1, 29) = 2.739, p = 0.109, \text{partial } \eta^2 = 0.086$). The simple main effects showed significant differences: *robot-didn't-speak* < *robot-spoke* in the *elevator-didn't-speak* condition ($p < 0.001$), *robot-didn't-speak* < *robot-spoke* in the *elevator-spoke* condition ($p = 0.040$), and *elevator-didn't-speak* < *elevator-spoke* in the *robot-didn't-speak* condition ($p < 0.001$).

The analysis of the robot's intelligence scale showed a significant difference in the *elevator* factor ($F(1, 29) = 4.838, p = 0.036, \text{partial } \eta^2 = 0.143$), in the *robot* factor ($F(1, 29) = 18.512, p < 0.001, \text{partial } \eta^2 = 0.390$), and in the interaction effects ($F(1, 29) = 18.560, p < 0.001, \text{partial } \eta^2 = 0.390$). The simple main effects showed significant differences: *robot-didn't-speak* < *robot-spoke* in the *elevator-didn't-speak* condition ($p < 0.001$) and *elevator-didn't-speak* < *elevator-spoke* in the *robot-didn't-speak* condition ($p < 0.001$).

The analysis of the robot's safety scale did not show significant differences in the *elevator* factor ($F(1, 29) = 0.972, p = 0.332, \text{partial } \eta^2 = 0.032$), in the *robot* factor ($F(1, 29) = 0.833, p = 0.369, \text{partial } \eta^2 = 0.028$), or in the interaction effects ($F(1, 29) = 0.207, p = 0.652, \text{partial } \eta^2 = 0.007$).

In summary, predictions 1 and 2 are partially supported. The participants had positive impressions of the elevator and the robot when they used voice cues in the context of likability and intelligence scales, except for the safety scale. Prediction 3 is not supported, i.e., the perceived impressions when both the elevator and the robot used voice cues are similar to when either one used voice cues.

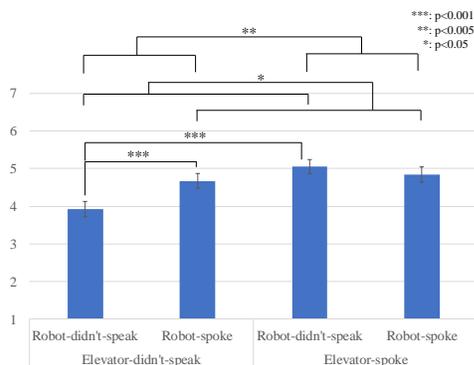


Figure 6. Questionnaire results of elevator's likeability (average and S.E.)

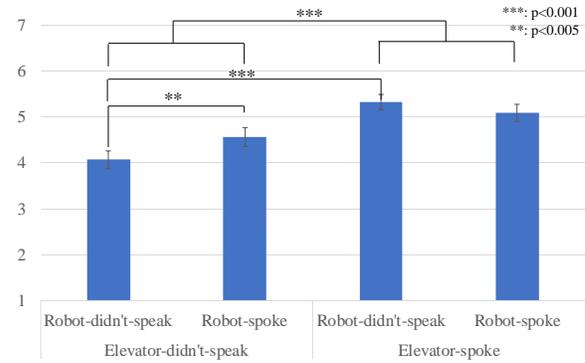


Figure 7. Questionnaire results of elevator's intelligence (average and S.E.)

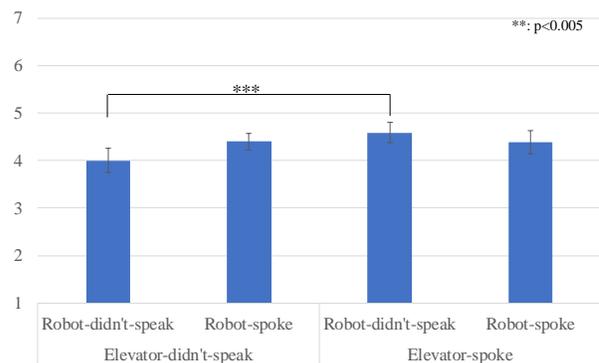


Figure 8. Questionnaire results of elevator's safety (average and S.E.)

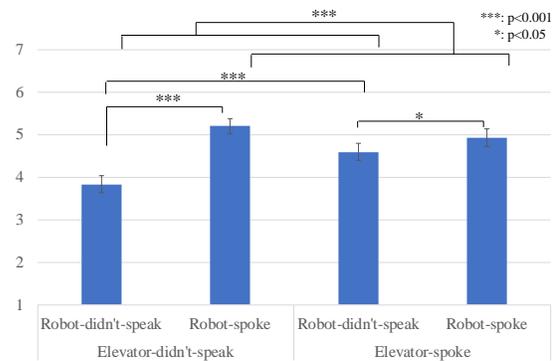


Figure 9. Questionnaire results of robot's likeability (average and S.E.)

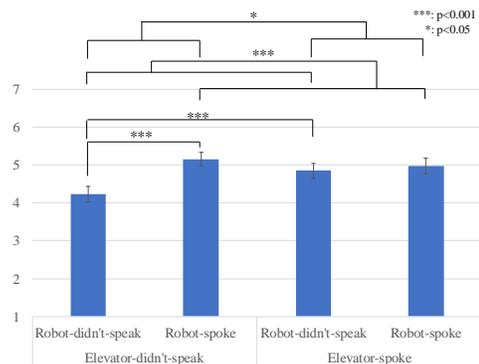


Figure 10. Questionnaire results of robot's intelligence (average and S.E.)

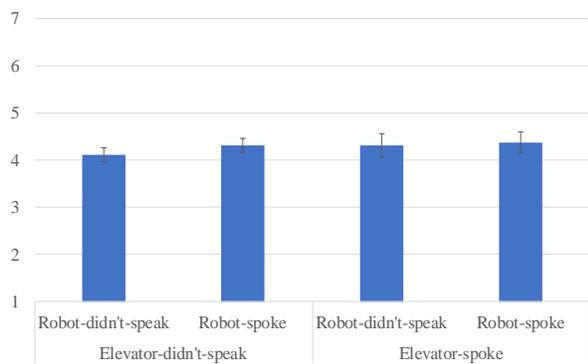


Figure 11. Questionnaire results of robot's safety (average and S.E.)

V. DISCUSSIONS

A. Implication

Our experimental results showed that voice cues improved the perceived impressions of both the smart elevator and the mobile robot, except for the perceived robot's safety, even though only one used voice cues. These results suggest a slightly different phenomenon compared to past studies that describe interaction among multiple robots [40]. A possible reason is the different context of interaction, i.e., waiting for the robot to take the elevator. Past studies focused on conversational interaction between robots and participants; our study focused on a specific and realistic situation when people and a mobile robot shared an elevator.

One interesting phenomenon is the complementary effects of voice cues between elevators and robots in the context of likeability and intelligence. The elevator's voice cues increased not only its own likeability/intelligence but also the robot's intelligence. The robot's voice cues increased both its own likeability/intelligence and the elevator's likeability. These results suggest that the difference in interaction style caused different complementary effects. Possible explanations for increasing the robot's intelligence from the elevator's voice cues are that participants may assume that the robot has the capability to communicate with the elevator. On the other hand, the robot's voice cues did not significantly influence the elevator's intelligence, although they increased its likeability. In this situation, the participants might have assumed that the robot was manipulating the elevator as a tool, and so the robot's voice cues did not influence the elevator's intelligence. One possible implication is that even if two agents do not each produce speech with equal amounts of information, the presence of two bodies may improve impressions simply by having one of them speak. In fact, since past related studies used two conversational robots that were designed to verbally express equal amounts of information in their tasks, the phenomenon observed in our study remains unconfirmed [40]. This may suggest the importance of investigating the effects of biased amounts of information in robots' conversations.

We believe the findings from our study provide more useful insight for elevator developers/researchers. Past studies related to the interaction between mobile robots and elevators mainly focused on how robots socially behave when they use or share elevators with people; evaluations of elevators have been limited. However, when people live in buildings, they frequently use and interact with elevators. From this

perspective, regarding them as social robots is important to achieve acceptable behaviors for them.

In reality, a smart elevator may communicate with a robot ahead of time to provide information to passengers while they are taking the elevator. Unfortunately, mobile robots, which have been simplified for commercialization, may lack voice interaction capabilities; in such cases, it would be useful to implement the ability to talk with people on the elevator side to gain greater acceptance of the robots from society.

Note that since voice cues have less influence on the perceived safety scale, another social behavior, such as moving trajectories, might improve the safety perspective.

B. Limitation

Our experimental results suffer from several practical implications. We used only one mobile robot and one specific elevator. During the experiment, which focused on a specific cultural focus (i.e., Japan), only one passenger rode the elevator. Future research will investigate the effects of different kinds of mobile robots, not limited to wheel-based types (e.g., multi-legged or android robots [41, 42]). Another limitation is that the order of the voice cues was fixed in the experiment, i.e., the elevator talked first. Nonetheless, despite these limitations, our study offers valuable insights for robotics researchers who are interested in designing robot-elevator interactions with passengers.

VI. CONCLUSION

Mobile robots are capable of moving around daily environments by taking smart elevators. Unfortunately, the boundaries of acceptable social behaviors when such robots ride them with passengers haven't been scrutinized yet. In this study, we investigated the voice cue effects of a mobile robot and a smart elevator on the perceived impressions of elevator passengers. We conducted an experiment with the WoZ approach, and its results showed the positive effects of the voice cues of an elevator and a mobile robot. The results did not show any combined effects; we found that either voice cue fostered positive impressions toward the other. Thus, the elevator's voice cue improved the perceived intelligence of the mobile robot, and the robot's voice cue improved the perceived likeability of the elevator. Such asymmetric interaction effects provide useful knowledge for both elevator/robot developers.

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