2013 IEEE/RSJ International Conference on
Intelligent Robots and Systems (IROS)
November 3-7, 2013. Tokyo, Japan

Picking Favorites: The Influence of Robot Eye-Gaze on Interactions with Multiple Users*

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Abstract—**We evaluated the effects of robot gaze behavior on interactions with multiple users in a museum-like setting. We posit that a robot needs to divide its attention between multiple users and may be able to use its gaze to 'point' at objects of interest. A 2 (person-oriented [only looking at participants] vs. object-oriented [also looking at artworks] gaze) x 2 ('favored' [looked at more] vs. 'not favored' [looked at less] by the robot) mixed factorial design (N=57) study was carried out in a museum-like lab setting where a robot talked about two artworks to groups of three participants. Results indicate that 'favored' participants did indeed pay more attention to the robot and the artworks. However, surprisingly they paid more attention when the robot did not look over to the object of interest compared to when it did give this gaze cue. The findings suggest that using an object-oriented gaze as a cue for people to look at an object may not carry across readily from person-to-person to human-robot communication. People had trouble interpreting the cue and were possibly distracted by the robot's movement.**

I. Introduction

During the last decades, several tour guide robots have been developed ([1–5]). In previous work, these guide robots' behaviors were found of importance in either smoothing or hampering human-robot interaction (HRI). Within the FP7 project FROG (Fun Robotic Outdoor Guide, www.frogrobot.eu), a robot is being developed that will guide small groups of visitors through outdoor tourist sites such as the Royal Alcázar in Seville, Spain. In order to inform design, not only of the appearance but also of the robot's interactive behaviors, navigation behaviors and synthetic personality, we will evaluate robot-specific guide behavior for several interaction modalities and combinations thereof to find what behavior works best in terms of engaging, entertaining and educating small groups of visitors.

In previous research we found that visitors liked to have time to observe exhibits at their own pace, they liked to receive information given by guides and they liked to engage socially with people in their own group [6]. Tours guided by human guides cannot provide for all these requirements, but the FROG-robot's design goals are to take this combination of requirements into account.

*The research leading to these results received funding from the European Community's 7th Framework programme under Grant agreement 288235. http://www.frogrobot.eu.

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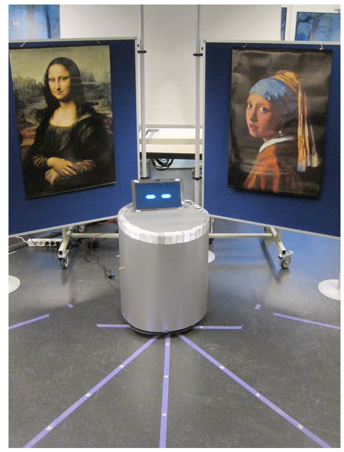

Figure 1 Impression of the Magabot robot in action

Human tour guides use several 'modalities' (e.g. pointing, gaze, body pose, facial expressions, speech) to gain the attention of visitors and to engage them during the tour. Particularly gaze is an important behavior that human tour guides use to keep people engaged, distribute their attention across a group, indicate objects of interest and direct peoples' attention [7], [8]. To understand the effects of robot gaze on the experiences of small groups of visitors, we performed an experiment where a robot interacted with three visitors while talking about two artworks (see Figure 1).

We compared two gaze conditions. In one condition - the person-oriented gaze condition - the robot looked at the three participants in the group intermittently. In the other condition - the object-oriented gaze condition - the robot looked at the participants just as in the previous condition but also looked over to the object (artwork) it was talking about. The robot gazed toward the artworks at specific moments in the story where a human guide would usually point to direct the visitors' attention to the artwork and establish joint gaze and shared attention toward the artwork. We expected the object-oriented gaze condition to have a more positive effect on the attitude of participants toward the robot and on the attention people paid to the object of interest and to the robot.

Next to gaze behavior toward the artwork, the robot should have attention for the visitors. Human tour guides normally do not distribute their attention evenly between people in the tour group. They alternate their gaze between visitors but also tend to focus more on one [7]. Robots that interact with multiple users will also need to distribute their attention across the group. As this will inevitably lead to unequal distribution of attention, we were interested to find out what the effects are of a robot 'favoring' one of the persons in a small group. The robot in our study looked more

978-1-4673-6357-0/13/$31.00

frequently and longer at one of the three participants whereas it looked less at the others.

This is a first study to explore how a robot should address small groups of users. The results shall inform the design of HRI with multiple users. We are particularly interested to find out whether multiple users do indeed engage in shared attention with a robot that displays object-oriented gaze and whether this influences their experience of the interaction.

II. Theoretical Background

When people interact, non-verbal communication plays an important role. Here is an example in the museum context: when visitors follow a guided tour and are not interested in the story anymore, they start looking around. In contrast, interested visitors direct their attention toward the point of interest or the guide [8]. Another example shows even more subtle non-verbal communication: when a human tour guide is about to finish a story at one exhibit, the guide already orients him/herself a little bit toward the direction of the next exhibit while giving the last bits of information. By doing this, the guide communicates to the visitors that the story will finish soon and in which direction they will go next [7].

As is found for computers, we tend to treat robots as social actors and as a result we react to them in a similar way as we do react to each other [9]. From previous HRI research we know that people adhere to social rules in person-to-person communication and they also judge robots according to such commonly held social norms [10]. Even when robots do not really have a human-like appearance, but only show human-like features or behavior, people tend to anthropomorphize [11]. The underlying assumption is that it is easier for people to understand human-like behavior, because it is recognizable and familiar. Therefore, it smoothens the HRI [12]. As people are familiar with human tour guide behaviors and because of the human tendency to respond socially to complex technology, the use of person-to-person communication modalities and cues can also be effective in the design of robot guide behavior, especially to attract, hold and orient people's attention.

For the purpose of this study, we focus on robot gaze behavior as a way of indicating or engaging in shared attention toward an object of interest. In person-to-person interaction, non-verbal cues to direct a conversational partner's attention can be given through gaze. Mutlu et al. [13] stated gaze direction is frequently non-verbal leakage of a person's focus or interest and they showed that robot gaze cues for humanoid and non-humanoid robots are effective in a human-robot dialogue. They found that people are able to understand subtle non-verbal communication cues produced by highly anthropomorphic robots as well as by robots with few anthropomorphic features.

Further studies confirmed that gaze behavior has great influence on HRI for example in proxemics. Mumm and Mutlu [14] found that participants ignored by a robot were more prone to get closer to it, while participants who were tracked across the room by the robot's eyes, were more likely to distance themselves from the robot. These findings suggest that such gaze behavior conveys agency and social norms may dictate keeping a polite distance. However, the head movements in themselves can also impact a conversation. Sidner et al. [15] found that in their study people reacted more often to a robot that made head-movements and gestured than to a robot that only talked. People reacted to the robot that displayed head movements, by changing their own gaze direction and engaging more in shared attention with the robot. Moreover, the robot that showed gaze cues was perceived as more reliable than the robot that only talked. Therefore, we believe that a robot could effectively use its gaze to direct a person's attention toward a particular object. We expect that for a robot guide, directing a visitor's attention toward an object with its gaze behavior will result in more attention toward the object of interest. We expect that if a robot steers the visitors' attention toward an object then the visitors will pay more attention to the information the robot conveys about the object. This leads to our first hypothesis:

Hypothesis 1: When a robot displays object-oriented gaze (looks at the participants as well as the object of interest), participants will pay more attention to the object and the robot, will remember more about the object and the story, and will have a more positive attitude toward the robot.

Next to gaze behavior toward the object, the gaze behavior toward the persons may influence the interaction. When interacting with groups of people, guides distribute their attention between the group, however, they do not do this evenly [7]. Human guides gaze at some people more than at others. Research on gaze in person-to-person interaction shows that the amount of gaze expresses and evokes liking as well as attraction [16]. People that are positively attracted to each other tend to gaze at each other more. Further studies report that in situations where gaze is interpreted positively rather than as an act of aggression, participants tend to comply more to requests from experimenters that gaze at them than to requests from experimenters that do not [16]. Another effect of robot gaze that has been found by Mutlu et al. [17] is that people tend to have better recall of a story told by a robot when the robot "looks at" them, even when the robot does not have functional eyes. Such an effect was derived from person-to-person interaction [18]. This leads us to consider that a robot guide that interacts with a small group will inevitably distribute its gaze unequally between the visitors regardless of the behavioral algorithm implemented. We are interested to find out whether this will be perceived as getting more attention from the robot. We expect that 'favored' visitors will like the robot more and will pay more attention to its story about the object of interest. We expect that when the robot displays object-oriented gaze, favored people will be more inclined to engage in shared attention toward the artwork. This leads to the second hypothesis:

Hypothesis 2: When a robot pays more attention to one participant in a small group, the 'favored' person will pay more attention to the object and the robot, will remember more about the story, and will have a more positive attitude toward the robot. Also, the 'favored' person will be more prone to engage in shared attention.

III. Study Design

We conducted a 2 (object-oriented vs. person-oriented gaze) x 2 ('favored' vs. 'not favored' by the robot) mixed factorial design study, where a robot guide talked about two artworks to groups of three participants.

A. Participants

57 Participants, students and staff members of the university, took part in the experiment (mean age was 25.6 (sd = 7.585); 41 male, 16 female). Of the participants 78.9% studied or worked in IT. 91.2% of the participants reported having little or no experience with robots. Slightly more than half (56.1%) of the participants had some previous knowledge about one or both artworks.

B. Robot

The platform used in the experiment was a Magabot-robot[1]. It came with a table-structure and a custom-made shell was used. The custom-made shell was very basic and had no anthropomorphic features. A laptop showing anthropomorphic eyes was placed on top of the structure of the platform. The robot turned its front toward the point it was looking at as well as moving its eyes to that side to indicate it was looking at a specific participant or at one of the artworks. See Figure 1 for an impression of the robot.

C. Manipulations

During each session of the experiment, the guide robot stood in front of two posters of famous artworks; The Mona Lisa and The Girl with the Pearl Earring. The robot told a story about both artworks to groups of three participants.

Favored vs. not-favored condition: While giving information about the artworks, the robot looked toward each of the participants and alternated its gaze between them. However, the robot focused on the person on the left, and alternated its attention at eight moments during the story to the persons in the middle and on the right for 1 to 2 seconds.

Person-oriented vs. object-oriented gaze condition: In the person-oriented gaze condition, the robot alternated its gaze between the three participants, as described above. In the object-oriented gaze condition, the robot also turned toward ("gazed at") the artwork it was talking about. The duration of the gaze was 2 to 6 seconds. The robot looked toward the artworks at moments when a human tour guide would point at the object. When the robot looked at the objects, it asked participants explicitly to look at the artwork ('please take a look at her hands'), or it was implicit about looking at the artwork ('the Mona Lisa is perhaps the most famous artwork in western art history'). 30 Participants interacted with the robot in the object-oriented condition, 27 participants interacted with the robot in the person-oriented condition.

D. Procedure

The experiment was performed in a lab at the University of Twente. The participants were welcomed in groups of three persons and informed about the study. All participants signed a consent form before entering the experiment room. Figure 2 shows the setup of the room. The participants were asked to position themselves on one of the three lines. The position of the participants was partly predefined, as they had to stand on a line drawn on the floor. However, the participants were able to choose their proximity to the robot. Also the lines were designed to place participants around the (robot) tour guide as they would be in real exhibition areas

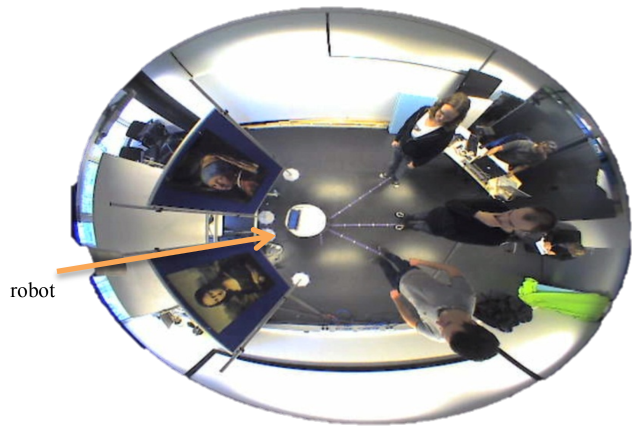

Figure 2 Top-view (fish-eye camera) of experiment setup

where they would stand common-focus gathering: in small groups a slight difference between speaker and group (oriented in semi-circle) becomes visible [19]. The robot was remote controlled by one of the experimenters in a Wizard-of-Oz setting. After listening to the robot's story about the two artworks, the participants filled out an online questionnaire individually on laptops provided to them. Each session took approximately 30 minutes. All sessions were video recorded.

E. Measures

To measure attitudes toward the robot, a questionnaire was developed using several validated scales. To measure *Trust* in the robot we used the sociability, competence, composure and character subscales of the 15 item Source Credibility Scale of McCroskey [20]. In addition, the subscales *Anthropomorphism*, *Likeability*, and *Perceived Safety* of the Godspeed Scale of Bartneck et al. [21] were used. The subscales *Attentional Allocation* and *Co-Presence* of the Social Presence Measure of Harms and Biocca [22] were used to measure perceived attention received from the robot and given to the robot and perceived co-presence with the robot. Table 1 shows the items and the reliability (Cronbach's alphas) of the subscales.

The items of the Source Credibility Scale and of the Godspeed Scale were measured on a 7-point semantic differential scale and the items of the scales were ordered randomly in the survey. The items of the Social Presence Measure were measured on a 5-point Likert scale, such as in the original questionnaires. Some items were added to mask the intention of the questionnaire; only one of the added items (safe-threatening) was used in the analysis, because by replacing the original item "quiescent-surprised" by this one improved the reliability of perceived safety.

Next to the questionnaires, we used video recordings to measure the *visitors' attention* more objectively. We annotated and analyzed the videos to examine where the participants looked at specific moments during the experiment. We annotated all seven instances of *explicit compliance* (people looked at the artwork when they were explicitly asked to look), and all seven instances of *implicit compliance* (people looked at the artwork because the robot turned and "looked" – only in the object-oriented mode but the same moments were annotated in the person-oriented

[1] www.magabot.cc

TABLE I. ITEMS AND RELIABILITY OF SCALES USED

Measurement	α
Source Credibility Scale	0.828
Good-natured – Irritable	
Cheerful-Gloomy	
Unfriendly-Friendly *	
Expert-Inexpert	
Unintelligent-Intelligent	
Intellectual-Narrow	
Poised-Nervous	
Tense-Relaxed *	
Calm-Anxious	
Dishonest-Honest	
Unsympathetic-Sympathetic	
Good-Bad	
Godspeed: Anthropomorphism	0.819
Fake-Natural	
Machinelike-Humanlike	
Unconsciousness-Consciousness	
Artificial-Lifelike	
Moving rigidly-Moving elegantly	
Godspeed: Likeability	0.829
Dislike-Like	
Unfriendly-Friendly *	
Unkind-Kind	
Unpleasant-Pleasant	
Awful-Nice	
Godspeed: Perceived Safety	0.704
Tense-Relaxed *	
Agitated-Calm	
Safe-Threatening	
Social Presence Measure: Co-Presence	0.752
I noticed the robot	
The robot's presence was obvious to me	
My presence was obvious to the robot	
The robot caught my attention	
I caught the robot's attention	
Social Presence Measure: Attentional Allocation	0.811
I was easily distracted from the robot when other things were going on	
The robot was easily distracted from me when other things were going on	
I remained focused on the robot throughout our interaction	
The robot remained focused on me throughout the interaction	
The robot did not receive my full attention	
I did not receive the robot's full attention	
* Only asked once, but used in both scales	

mode for comparison) and *general attention* (number of times people looked at the artwork or at the robot, measured at fixed times during the experiment, 20 events every 30 seconds). Participants who looked at the robot or the artworks were considered to be paying attention to the story and participants who looked elsewhere were considered to be distracted.

To measure *likeability* we also used proxemics: participants chose their own position (on a line) and could move freely toward or away from the robot. In accordance with Mumm and Mutlu [14] we assumed that the closer the participants stood, the more they liked the robot. The distance between participants and robot was measured at three times through the experiment. First, when the participants positioned themselves at the start of the narrative. Second, halfway during the story. The last measurement was taken at the end of the story, when the robot said goodbye.

To obtain insight into the *recall* of details of the stories and the artworks, the participants had to answer some knowledge questions individually, as part of the questionnaire. There were three kinds of questions. 1) questions about details mentioned in the story and visible in the artwork, 2) questions about details mentioned in the story only and 3) questions about details visible in the artworks only. For each knowledge question three possible answers and the option "I can't remember" were presented.

F. Data analysis

The questionnaire-data were analyzed using SPSS. All scales were first tested for reliability, using the Cronbach's alpha coefficient. After tests of normality, two-way ANOVA's were run to test the main hypotheses.

Video data was pre-processed and only parts that showed participants listening to the robot's story were used. The videos were annotated by two researchers, which were tested for inter-rater reliability. The annotators scored attention-direction of the participants; that is whether the participants were looking at the robot or the artwork (showing attention), or the participants were looking away (showing no attention). We annotated three different events - explicit compliance, implicit compliance and general attention. The overall similarity of all annotations was 91%. However, the inter-rater reliability Kappa turned out to be 0.514, which means a moderate agreement. This low Kappa is likely due to the Boolean scoring (no attention-attention). For the analysis of the video annotations, the annotations of one of the researchers were used without preference.

IV. RESULTS

The manipulation of 'favoritism' was checked with one survey item that asked who the robot had looked at most. The majority of the participants indeed noticed that the robot looked more at one of the participants, indicating that the manipulation was successful. 44 of 57 people (77.2%) responded correctly that the participant on the line at the side of the Girl with the Pearl Earring was favored. Only 4 of 57 (7%) responded the participant on the line in the middle was favored, and the remaining 9 (15.8%) responded that they did not know. None of the participants responded that the participant in front of the Mona Lisa was favored.

The manipulation check for 'gaze condition' was done by analyzing the video data. We expected that when the robot looked at the artwork, participants would also look at the artwork and thus engage in shared attention. However, we did not find this. Instead, we found that participants in the object-oriented mode paid more attention to the robot at explicit compliance moments ($F[1,35] = 25.395$ $p = 0.000$) and at implicit compliance moments ($F[1,35] = 21.902$, $p = 0.000$) than participants in the person-oriented mode. Instead of directing attention to the object, it seems that the robot's (gaze) movement drew attention to the robot. This means we successfully drew people's attention with the object-oriented gaze behavior but were not successful in creating shared attention toward the art object.

Hypothesis 1 concerned the expectation that participants in the object-oriented gaze condition (the robot looked at the participants and also at the artwork) would pay more attention to the object and the robot, would remember more about the object and the story, and would have a more positive attitude toward the robot.

In fact, participants interacting with the robot in the object-oriented gaze condition tended to perceive the robot as more human-like ($F[1,53] = 3.844$, $p = 0.055$) than participants that were exposed to the robot looking at participants only. Also, these participants (M = 1.39m) stood significantly closer to the robot halfway through the interaction ($F[1,53] = 4.167$, $p = 0.046$) than participants in person-oriented gaze condition (M = 1.58m). Overall, during the story, the difference in proximity between participants in object-oriented mode (M = 1.39m) and person-oriented mode (M = 1.58m) was marginally significant. The participants in the object-oriented mode tended to stand closer to the robot ($F[1,53] = 3.595$, $p = 0.063$). No differences in recall of story or artwork details were found between groups. Also, no differences in general attention between groups were found. With these results hypothesis 1 is partly supported.

Hypothesis 2 concerned the effect of a robot paying more attention to one of three participants. Expectations were that the 'favored' person would pay more attention to the object and the robot, would remember more about the story the robot told, and would have a more positive attitude toward the robot. Also, favored persons were expected to be prone to engage in shared attention in the object-oriented condition.

Results indeed showed that favored participants perceived more attention received from the robot and more attention given to the robot ($F[1,53] = 91.740$, $p= 0.000$) than non-favored participants. Also, favored participants found the robot more present and felt the robot to be more aware of their presence ($F[1,53] = 37.786$, $p = 0.000$) than their non-favored colleagues. Furthermore, we found that favored participants tended to like the robot more ($F[1,53] = 3.737$, $p = 0.059$) compared to non-favored participants.

A marginally significant main effect was found for being favored at implicit compliance moments ($F[1,35] = 3.390$, $p = 0.074$). Favored participants tended to look less at the robot and more at the artwork than non-favored participants in both gaze conditions. Results also showed a surprising interaction effect between gaze condition and being favored at explicit compliance moments. In the person-oriented mode, the participants looked more at the artwork when the robot told them explicitly to do so than participants in the object-oriented mode ($F[1,35] = 5.218$, $p = 0.029$). This effect more strongly influenced participants that were favored by the robot (object-oriented mode M = 0.83, sd = 0.21; person-oriented mode M = 1.00, sd = 0.00) than the non-favored participants (object-oriented mode M = 0.95, sd = 0.07; person-oriented mode M = 0.97, sd = 0.06). The values indicate the probability that a participant is looking at the artwork. This shows that contrary to our expectation, especially favored participants had more attention for the artworks in the person-oriented mode rather than the object-oriented mode. At moments of explicit compliance another interaction effect showed that participants looked more at the robot and/or artwork in the person-oriented mode ($F[1,35] = 4.476$, $p = 0.042$) rather than the object-oriented mode. Favored participants in the person-oriented mode looked significantly more at the artwork or the robot than favored participants in object-oriented mode. For non-favored participants this trend seemed to be the other way around, but was not significant.

V. DISCUSSION

The results above only lead to partial acceptance of hypothesis 1. However, participants in the object-oriented mode found the robot more human-like and the participants' attention indeed was attracted toward the robot, participants in the object-oriented gaze condition did not pay more attention to the artwork compared with the person-oriented condition. Also, there were no differences in remembering the story between participants in object-oriented mode and person-oriented mode

These results seem to indicate that robot movements related to gaze behavior do indeed draw attention as indicated by Sidner et al. [15] but do not necessarily direct the visitors' attention to the object of interest as expected. We found that people did not engage in shared attention with the robot but instead focused more on the robot. We know that people very effectively direct other people's attention with directed gaze behavior [23], however, in this study the same behavior copied one-to-one to a robot resulted in more attention toward the robot rather than the object of interest. This makes us conclude that implementing functional gaze behavior in a robot to direct visitors attention (as an effective alternative for pointing) does not carry across easily from person-to-person communication to HRI.

The findings only partly support hypothesis 2 as well. Favored participants did indeed perceive the robot as paying attention to them and felt the robot was aware of them, indicating a more positive attitude toward the robot. They tended to like the robot more than the non-favored participants. However, favored participants did not show a better recall of details and did not stand closer to the robot than non-favored participants did.

The results indicate differences between being favored or not, however the differences are not as expected. Favored participants did not remember the story better, while they did in the study of Mutlu et al. [17], which might be due to the distraction of the moving robot. Also, favored participants tended to like the robot better, but they did not stand closer than the non-favored participants, while we would expect that result based on Mumm and Mutlu. [14]. However, this effect probably is caused by influences of the other group members.

Overall, we found that people reacted to movements of the robot, as Sidner [15] stated in previous work. Our findings are not completely in line with the results of Mutlu et al. [13] who found that people understand non-verbal communication cues intuitively when applied to robots. In our study, people did not interpret the robot's gaze cue as a signal to look at the artwork. We found the robot less effective in creating shared attention with gaze. Perhaps the robot's movements distracted people and drew their attention toward the robot rather than engaging them in shared attention toward the object. This could indicate that a typical social gaze cue ('look at this object') carried out by human guides is interpreted differently when displayed by a robot.

In the person-oriented gaze condition, the robot kept its gaze on the participants throughout the interaction. We know from previous work that people tend to comply when they are being gazed at as a request is made [16]. Perhaps this explains participants' compliance to the robot's request to look at artworks in the person-oriented mode.

VI. Conclusion and Future Work

The results indicate that participants interacting with a robot with object-oriented gaze behavior had a more positive attitude toward the robot, but paid less attention. This result indicates that an object-oriented gaze pattern is preferred by people, but that subsequent research is needed to develop a more intuitively understandable gaze pattern in such a way that it effectively directs the visitors attention toward objects of interest. For robots interacting with multiple users, we found that participants that received more attention from the robot liked the robot better.

Limitations of the current experimental set-up mostly involved the difficulty in establishing exactly where each of the participants was gazing. However, future work will include a more detailed analysis of the gaze patterns of the participants. We expect these analyses will explain whether favored participants in object-oriented gaze conditions have (overall) higher attention than other participants. Also, this analysis might help to support the hypotheses more firmly.

Even though we artificially created a situation where three people interacted with a robot, their orientation was comparable to the orientation of visitors around a human tour guide. Therefore, we can use the study findings that clearly show differences in attitudes and behavioral responses toward the robot. Future research should be carried out 'in the wild' to explore whether more spontaneous encounters between people and robots yield the same results.

Logical next steps to further this work will also involve investigation of other modalities for effective pointing behavior, effective addressing of small groups and effective guiding of visitors' attention. The current study involved a one-on-one translation of human guide behaviors to robots. We think that there may be robot-specific alternatives that are easier to interpret by visitors and that will more successfully allow directing people's attention to objects of interest.

Acknowledgment

We would like to thank S. Bos and M.P. Joosse for helping during the experiment and data analysis.

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