Hey! There is someone at your door. A Hearing Robot using Visual Communication Signals of Hearing Dogs to Communicate Intent

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***Abstract*—This paper presents a study of the readability of dog-inspired visual communication signals in a human-robot interaction scenario. This study was motivated by specially trained hearing dogs which provide assistance to their deaf owners by using visual communication signals to lead them to the sound source. For our human-robot interaction scenario, a robot was used in place of a hearing dog to lead participants to two different sound sources. The robot was preprogrammed with dog-inspired behaviors, controlled by a wizard who directly implemented the dog behavioral strategy on the robot during the trial. By using dog-inspired visual communication signals as a means of communication, the robot was able to lead participants to the sound sources (the microwave door, the front door). Findings indicate that untrained participants could correctly interpret the robot's intentions. Head movements and gaze directions were important for communicating the robot's intention using visual communication signals.**

Keywords—robot behaviour, human-robot interaction; robotic home companion; social robot

I. Introduction

The design of robot behaviour has often drawn on human-human interactions for inspiration when considering communication behaviors for social robots [1]. This is often considered a logical design choice when robots interact with humans. However, designers and researcher are also exploring potential interaction modalities that human users may be familiar with from human-animal interactions. Importantly, with human-animal interactions people usually do not make great assumptions of human-like cognition and intelligence in their interaction partners. In the current study, we therefore explored other modalities with the aim to complement and improve the design of behaviors for social robots. Human dog interaction is one of the interaction modalities we are particularly interested in since dogs have been known to be reliable companions for humans [2]. They are capable of communicating their intent to their owners successfully using visual communication signals [3][4][5][6] generated from a selection or combination of non-verbal sounds, touch, body and head movements. Miklósi and Gácsi [7] have suggested that human-dog interaction can be used as a source of inspiration for designing social behaviors for robots that are to interact with humans in various situations, while Dautenhahn [8] suggested that we can learn from social relationships between dogs and humans to guide the development of robots we like to live with. However one of the key features that make human-dog interactions so successful is that humans attribute intentions to dogs when interacting with them. This could be useful to enhance the believability of a social robot and to enrich human-robot interactions.

Researchers have shown that it is important for robots to have appearances that match their functionalities [9] as users often assign the functionality of the robot based on its appearance [10]. Similarly, it is important for the robots to use interaction modalities that match users' expectations. This can be achieved by matching robots' interaction modalities with their appearances. Initially users may pick up on relatively familiar aspects of a particular robot's appearance and behavior to guide their interaction with the system. Mobile robots, both in terms of capabilities and appearance, have some attributes which are dog-like, making these modalities feasible and intuitively valid [11]. Likewise, Friedman et al. [12] and Jacobsson [13] suggest that zoomorphic appearance and behavior can be a very effective means for a robot to encourage continued interactions with the user. Using a mobile robot, without a zoomorphic appearance but imitating some aspects of dog-like behaviour, will allow researchers to focus on exploiting dog-inspired communication signals without raising users' expectations with regards to dogs' abilities [14]. The broader aim is to extract efficient and life-like behaviours from the dog behaviour repertoire and apply a relevant set in "ANY" robot. The embodiment (outlook and capacities) of the robot should be fitted to its actual functionality, which could be very different than zoomorphic. We believe that dog social behaviour (communication of intentions and emotions + referential communication) includes many highly redundant elements from which we can always select the ones that suit a particular task and embodiment.

In order to study how people perceive dog-inspired robot behaviors we performed an experiment which involved a "Hearing Robot" HRI scenario. This was motivated by the behavior of hearing dogs that rely on visual communication signals to communicate and to provide assistance for their deaf owners [15]. The robot behaviors created for this study were designed by emulating various signaling and leading behaviors performed by certified hearing dogs when faced with similar

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situations to those faced in the scenario. The study focused on two main research questions:

RQ1: Can human participants attribute intentions to robots based solely on visual communication signals?

RQ2: Can untrained human participants comprehend the robot's intentions correctly?

Note, the aim of the research study presented here is not to replace dogs for deaf users with robotic alternatives, but rather to investigate an alternate behaviour paradigm that can be used to guide the design of intuitive robot communicative behaviours. In our case, these were dog inspired behaviours such as "attention seeking, leading and showing" that can be applied in a broader sense. The deaf owner scenario was one of several possible scenarios, but which was particularly well suited for modeling the behaviour patterns within an experimental setting.

II. METHODOLOGY

To investigate the research questions presented above, we first studied hearing dog scenarios where trained hearing dogs were successful in using visual communication signals to assist their owners attending to significant environmental sounds sources that require attention in their daily life. These sound sources range from the front door (e.g. a visitor ringing the doorbell) to the sounds emitted by the owner's mobile phone (e.g. when the owner receives SMS messages).

The experimental study was performed by an interdisciplinary team of HRI researchers together with ethologists from the Department of Ethology of Eötvös Lóránd University, at the University of Hertfordshire Robot House. Dog behaviors that were identified as the main visual communication signal used by hearing dogs, were adapted for the Sunflower robot, which is specifically designed for enacting human-robot home assistance scenarios.

In the study, the robot was controlled by an experienced operator using the Wizard of Oz paradigm [16]. The wizard was trained with hearing dogs strategies (see section II.C) prior to the study.

A. *University of Hertfordshire Robot House*

The University of Hertfordshire (UH) Robot House provides an ecologically valid domestic environment, compared to laboratory conditions for HRI studies. The UH Robot House is a fully furnished British house with two floors and four bedrooms. Only the living room, front hall, and the kitchen were used for this study.

B. *The Sunflower Robot*

The UH Sunflower robot used in this study was designed and built at the University of Hertfordshire as a research platform for the study of Robotic Home Companions. It was built on top of a commercially available Pioneer P3-DX mobile base [17]. It has a minimally expressive head with a static face (see Fig.1), a speaker capable of playing midi tunes, a diffuse color LED display panel located on its shoulder and a slide out carrying tray with an integrated touch screen user interface to facilitate user interaction. This allows the robot to exhibit different channels for expressing its internal states by utilizing body and head motions, sound tunes, and color LED display panels. Researchers can use the robot to explore different modalities for creating effective expressive behaviors for robots in different human-robot interaction scenarios.

For this study, the Sunflower robot's tray, touch screen and arms were deactivated. Using three expressive channels, head movement, body movement and color LED display, the robot was pre-programmed with dog-inspired Attention Seeking, Gaze Alternation, Looking Back and Happy behaviors. These particular behaviors were required for the robot to express visual communication signals suitable for the hearing robot scenario. The robot behaviors were based on dog behaviors observed in similar human-dog scenarios. These were adapted to the Sunflower robot's embodiment. The adaptation phase involved finding how to maintain the movements that convey the robot's intention, while making sure the behaviors can be expressed in a way that looks natural and feels organic to the user. The behavior sequences were mapped to specific keys on the keyboard to allow the wizard to have easy access to them during the trial.

Figure 1. The Sunflower Robot in the UH Robot House.

C. *Visual Communication Signal*

1) Hearing Dog

Typically, in a real hearing dog scenario (see Fig. 2) when a doorbell rings, a hearing dog will start by getting the attention of the person. This interaction initiation is usually expressed with touching behavior (Attention Seeking). The dog will start nosing the person. If this behavior is not effective enough (e.g. the owner is sleeping), it will then try pawing them. Once the dog obtains a person's attention, it starts to lead the person towards the front door. This leading behavior involves moving toward the target location while constantly checking (Looking Back) if the person is following or not. Depending on the person's actions, the dog will respond using the following strategies:

- If the person is not following the dog, but is oriented towards the dog's location (i.e. trying to understand the dog intention), the dog will continue moving toward the front door while still constantly checking the person's actions.

- If the person is ignoring the dog (i.e. not following and not looking at the dog), it will approach that person to re-attract their attention and then continue moving towards the target location, while constantly checking if the person is following.
- If the person is following, the dog will continue moving until it reaches the target location and stop.

Once the dog arrives at the target location, it will start directing the person's attention towards the object of interest. This attention-directing behavior involves turning its body to face the target object while performing Gaze Alternation between the person's face and the target object, as if indicating that it "wants" the person to interact with the object. If the person does not approach to interact with the target object, the dog will then move closer to the target object and continue Gaze Alternation between the person's face and the target object. This will continue until the person interacts with the target object. Fig. 2 shows an example of a hearing dog showing its owner to the door.

Figure 2. Example of a hearing dog using visual communication signals to guide its owner to the front door

2) Hearing Robot

Based on the dog's visual communication signals described above, we created a behavioral strategy flow chart, which allowed the robot's behaviors to be controlled in a standardized way during the trials (see Fig. 3). Three relevant dog-inspired behavior sequences were also implemented to support the overall visual communication cues needed for the robot to perform the hearing dog function. These three primitive behaviors are Attention Seeking, Looking Back (with synchronization of head and body movements, see Fig. 4) and Gaze Alternation (between target person and object). This flow chart was then used to train the wizard on the detailed sequences and strategies needed for controlling the robot throughout the hearing robot scenario. The behavior sequences can be described in 3 key stages:

a) Attention getting.

b) Leading – moving ahead, checking whether the user follows after starting and moving to target.

c) Showing target – using any body part to point or showing by orienting towards target, then perform gaze alternation between target and the user.

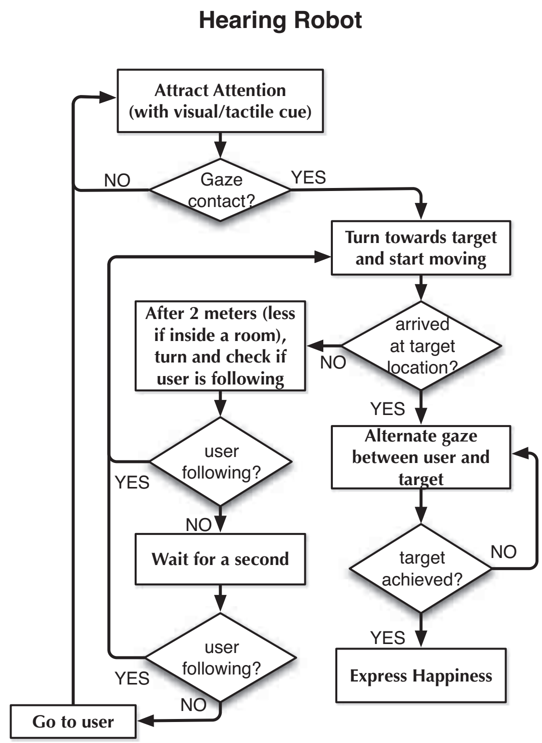

Figure 3. Flowchart of dog-inspired hearing robot behavioral strategy

Based on the flow chart, a 'hearing robot' will approach the user to initiate interaction. It will then use Attention Seeking behavior to attract the user's attention. Attention seeking behavior involves the robot moving forward and backward while rotating its head to the left and right and flashing a green light on its 'shoulder' (the part below the robot's neck) in front of the user. This behavior gives an impression analogous to that of a dog jumping up and down on the user's knee, except that the robot does not touch the user. The attention seeking behaviour used in this context may appear intrusive but it was necessary, otherwise it would take too long to attract the users' attention to urgent events (e.g. a postman would leave, food could burn or the bathtub might overflow). As stated in previous section, a major strategy of hearing dogs is using tactile signaling (i.e. using its nose or paw) to attract the people's attention, but this was not considered in this paper on the grounds of ethics as it might have posed a potential hazard for the participants.

Figure 4. Sequences of Sunflower robot performs dog inspired Looking back behavior.

If the user shifts their attention to the robot by looking at the robot, this will initiate the robot's leading behavior. This involves turning its body quickly and moving ahead toward the target location while constantly checking if the user is following using the Looking Back behavior. This behavior involves the robot turning both its body and head in a synchronized manner (this body movement is intended to compensate for the neck's, so it will not be making a large and unrealistic turn) to convey checking the signal. If the user looks at the robot or starts following, the robot will turn to face the target and continue moving towards the target location while continuing checking whether the user is still following. However if the user does not follow, the robot will wait for 1 second to see if the user will start to look at it or start following. If this does not happen, it will turn and move towards the user in order to try to attract their attention again.

Once the robot arrives at the target location, it starts directing the user's attention towards the target object using its Gaze Alternation behavior. This involves the robot switching its gaze between the user and the object of interest (i.e. turns its head to the user to establish joint attention, and then turn its head to face the target object). If the user does not understand the robot's intention, it will move closer to the target object (if allowed by the navigation safety limit) and continues with gaze alternation. If the user opens the door of the target object, the robot will then express its 'happy' behavior. This involves the robot rotating left and right on the spot while its head moves up and down. The robot will then return to its charging station and shuts down.

D. Experimental Setup

1) Hearing Robot Scenario

The scenario used in this study was based on the hearing dog scenario. In this scenario the robot had to lead the participants within the house to either open the front door or to open the microwave door. The robot only utilized dog-inspired visual communication signals to communicate its intent to the participants.

2) Participants

The sample consisted of 16 participants, 8 male and 8 female. The mean age was 26 years, with a median age of 23. The sample was recruited using advertisements on the University of Hertfordshire's intranet and consisted of students and staff from a variety of departments at the University.

3) Experimental Procedure

Three experimenters were involved in the trial. A psychologist introduced and explained the trial procedure, handed out questionnaires to the participants and answered any questions participants might have about the trial. A roboticist, who designed and programmed the robot's behaviors, acted as the wizard controlling the robot during the trial. An ethologist who helped design the robot's behaviors was also present, monitoring the trial. During the trial, only the roboticist and the ethologist were present in the living room with the participants. The participants were told that the experimenters were there to ensure everything ran smoothly and that they should ignore the experimenters during the trial.

Introduction: Participants were introduced to the UH Robot House and also to the Sunflower robot which was located at its charging station. They signed a consent form and completed a demographics questionnaire, which included questions about their experiences with technology and robots.

The participants were asked to sit on a sofa, read a novel and to behave as naturally as they would in their own home. They were told to imagine that the Sunflower robot belonged to them and that they had a hearing problem. To simulate a hearing impairment, they were asked to put on an over-ear noise-cancelling headphone, which played a neutral music loop to mask any environmental noise. The reason behind the simulated deafness was to create a valid experimental design which ensured that participants' behaviours were only influenced by the dog-inspired robot's visual communication signals and avoid participants using the doorbell or microwave sounds as contextual cues to help them understand the robot's visual communication signals. They were told that at some point during the session the robot might or might not approach them, and that during the trial they were free to do what they like.

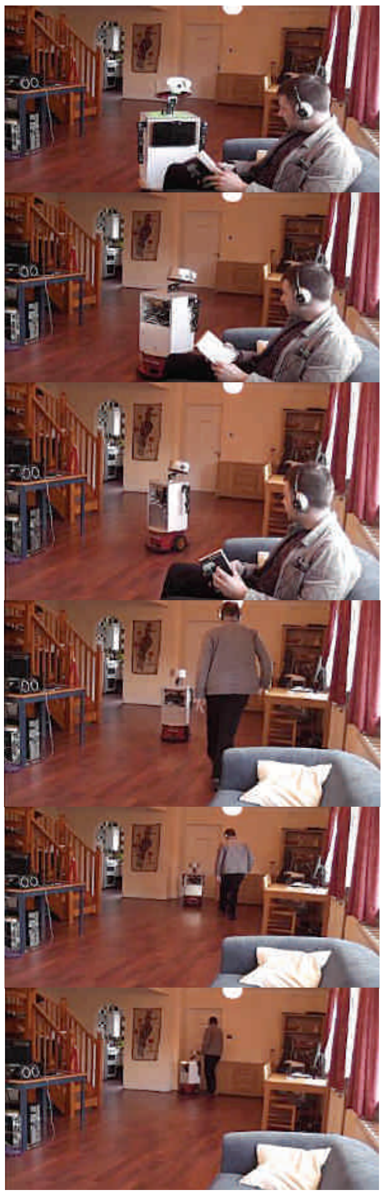

Figure 5. Sequences of Sunflower robot assisting the participant in the University of Hertfordshire Robot House during the Hearing Dog Scenario

Main Trial: The trial consisted of two different conditions. Depending on the condition, the robot would led the user to different target objects. The two conditions were:

Condition Microwave: The robot led the participant to the kitchen to open the microwave door.

Condition Front Door: The robot led the participant to open the front door.

The conditions were counterbalanced so that half of the participants started with Condition Microwave and ended with Condition Front Door, and vice versa. Thirty seconds after the trial start, the robot approached the participant to initiate the first interaction condition and led them to the target object that required their attention. If the robot failed to encourage the participants to follow after 300 seconds, or failed to get the participants to open the door of the target object after 360 seconds, the wizard terminated the current test condition. Either by driving the robot back to its charging station before proceeding to the next condition or to end the trial if both conditions had been completed.

Questionnaires: Participants were initially given a questionnaire containing demographics questions, the TIPI [18] measure for personality, and the Negative Attitudes towards Robots Scale (NARS) [19]. In addition, the participants were given a series of ad-hoc items related to their attitudes towards robot companions. In particular, they were asked how they would like to interact with, and have, their own robot companion.

Once the participants completed the main trial they were given a questionnaire to obtain their views on the trial scenario. They were asked to describe what they thought the robot was trying to achieve through its behavior, how they would characterize the robot and which behaviors were the most important in recognizing its intentions (if any?). They were also asked to rate how important each of the robot's expressive channels (head movement, LED display, body movement and movement synchronization) were in contributing to recognizing the robot's intentions. Fig. 5 shows an example of a trial where the hearing robot showed the participant to the door.

III. RESULTS

A. Understanding of the robot's intention during the HRI trial

For the front door condition, 12 out of the 16 participants correctly guessed the robot's intention and acted upon it. For the microwave door, 8 participants correctly guessed the robot's intention and acted upon it. In both cases the participants were able to solve the task within a mean time of 200 seconds.

Table I shows the relationship between the two tasks. There were no significant deviations from expected counts (Fisher's exact p=.118). There was a non-significant trend suggesting that participants that did not succeed in one of the tasks were less likely to succeed on the other. There were no significant, nor -salient effects due to presentation order.

B. Idiosyncratic Factors

There were no significant effects of Gender, Age or Pet ownership on the likelihood to succeed. Personality traits did seem to have some impact on success. Table II suggests that for the Front Door task, participants that succeeded on the task had a significantly lower conscientiousness than those who did not succeed.

For the Kitchen task, there was a trend mirroring this result for conscientiousness. In addition there was a trend approaching significance in which participants that succeeded on this task had lower scores in agreeableness.

C. Attitudes Towards Robots

Attitudes towards robots were measured using the Negative Attitudes towards Robots Scale (NARS) as well as a series of ad hoc questionnaires focusing on how participants preferences for interacting with robots. There was no significant effect for these measures compared with success in the Front Door task. There were, however, some salient results for the Microwave task. These are described in Table III. There was a trend approaching significance in which participants succeeding in this task would have a higher score in Subscale 3 of the NARS (Negative Attitudes towards Emotions in robots) than those who did not. Also, participants succeeding in the task tended to agree with the statements regarding wanting to care for a robot and willingly buying a robot, to a lesser extent than those who did not.

D. Specific Behaviors

Participants were asked which of the robot's behaviors were the most important in terms of communicating its intentions. This was done both by ratings on Likert scales as well as open-ended answers. The responses to the open-ended questions were classified and coded. Responses could belong to more than one category. The categories and their frequencies are reported in Table IV. Note that these categories are derived from the participants' responses and as such contain both basic movements as well as described behaviors that necessitate a higher degree of intentionality such as gaze and feedback. Table IV suggests that the single most referenced behavior was gaze and head movement, highlighting the importance of gaze as a means to disambiguate deictic communication.

The participants were asked to rate the robot's behavior in terms of importance ranging from 1 (Absolutely Not Important) to 5 (Very Much Important). The items along with their descriptive are found in Table V. There were significant differences between the items (Friedman's $\chi^2(3)=20.7$, $p<.001$) and a subsequent pairwise comparison using Wilcoxon Signed Rank tests suggested that this was due to Head Movement being ranked higher than the other behaviors listed ($Z>-2.831$, $p<.005$). These results suggest that participants to a large extent relied on the robot's head movement and, as suggested by the open-ended measure, specifically the robot's gaze to succeed at the task.

TABLE I. SUCCESS ACCORDING TO TASK

			Microwave	
			No	***Yes***
Front Door	***No***	***Observed Count***	3	1
		Expected Count	1.5	2.5
		Std. Residual	1.2	-0.9
	Yes	***Observed Count***	3	9
		Expected Count	4.5	7.5
		Std. Residual	-0.7	0.5

TABLE II. PERSONALITY AND SUCCESS

Task	Personality Trait	Success	Score	Mean Diff.	t-value (df)
Front Door	***Extraversion***	Yes	6.00	-0.38	-0.62 (13.78)
		No	6.38		
	Agreeableness	Yes	6.63	-0.25	-0.79 (13.73)
		No	6.88		
	Conscientiousness	Yes	5.92	-1.46	-2.72 (12.73)**
		No	7.38		
	Emotional Stability	Yes	6.83	-0.04	-0.07 (5.20)
		No	6.88		
	Openness	Yes	6.96	-0.17	-0.34 (4.95)
		No	7.13		
Microwave	***Extraversion***	Yes	5.90	-0.52	-0.68 (13.55)
		No	6.42		
	Agreeableness	Yes	6.40	-0.77	-1.95 (12.80)*
		No	7.17		
	Conscientiousness	Yes	5.80	-1.28	-2.07 (14.00)*
		No	7.08		
	Emotional Stability	Yes	6.80	-0.12	-0.20 (10.10)
		No	6.92		
	Openness	Yes	7.00	0.00	0.00 (11.50)
		No	7.00		

*approaching significance, p<0.1

**significance, p<.05

TABLE III. ROBOT SPECIFIC MEASURES AND SUCCESS

Task	Measure	Success	Score	Mean Diff.	t-value (df)
Microwave	***NARS Subscale 3***	Yes	3.22	0.72	1.80 (13.00)*
		No	2.50		
	I would enjoy if I had a companion robot who I had to care for.	Yes	3.20	-2.80	-2.32 (10.47)**
		No	6.00		
	I would willingly buy a companion robot for myself.	Yes	5.92	-3.13	-2.88 (13.99)**
		No	7.38		

*approaching significance, p<0.1

**significance, p<.05

TABLE IV. IMPORTANCE OF ROBOT BEHAVIORS FOR COMMUNICATING INTENTIONS

Category	No. of Responses	% of Responses
Gaze	10	62.5%
Head Movement	8	50.0%
Body Movement	3	18.8%
Feedback	5	31.3%
Lights	4	25.0%

TABLE V. IMPORTANCE OF ROBOT BEHAVIORS

Item	Mean	SE	Median
Head Movement	4.88	0.09	5.00
Lights	2.75	0.42	2.50
Body Movement	3.47	0.36	4.00
Movement Synchronisation	3.31	0.25	3.00

IV. DISCUSSIONS AND CONCLUSSION

The results show that participants were able to understand the dog-inspired visual communication signals expressed by the robot, and acted upon them to solve the problems even though they were not specifically told about the aim of the study. These results show an improvement, in terms of a robot using visual communicational signals to communicate intention, over a similar study [20] where the majority of participants failed to understand the robot's intention (i.e. seeking help to open the door) from five increasingly urgent non-verbal robot behaviors (i.e. using visual and sound cues). In this previous study, participants only responded to the sixth behavior where the robot explicitly asked for help using speech (i.e. "please can you help me open the door".)

In the current study, it is not a surprise that more participants were able to solve the Front Door problem as compared to the Microwave door problem. This may be due to the location of the microwave being in a more cluttered environment (a small kitchen), and it was located on a countertop that is higher than the robot's embodiment. Hence it is more difficult for participants to interpret the target of the robot's gaze as there were two other possible target objects, 1) drawers beneath the countertop (which the robot's body is facing), and 2) the cupboard above the microwave. For the front door condition, it was much easier for the participants to identify the target object based on the direction the robot's body was facing.

The function of the robot during the trial can be classified as a Reminder Task for the microwave condition, and a Notification Task for the front door condition. In a typical Reminder Task scenario, such as cooking or warming up food in a microwave, the user would already have established the context by putting their food in the microwave. The robot in this situation would likely have a better success rate in getting the user to open the microwave door, since it only needs to lead the user into the kitchen/location close to the kitchen. This would help the user to recall their previous activity based on the current contextual information.

Furthermore, in a real life scenario, a deaf person is aware of the abilities and cooperative intentions of their assistant dog. Therefore they pay attention to the dog's signals without hesitation. In our study, however, participants were not explicitly informed about the role of the robot (or the aim of the study), in order to observe the participants' spontaneous reactions. Informing the users in advance of the study context and scenario would likely have increased recognition rates.

The individual difference data suggests that a successful completion of both tasks is associated with a lower score of Conscientiousness. One possible explanation is the negative relationship between this personality trait and a more intuitive thinking style [21]. The ambiguity of the task and the nature of interpreting non-verbal information might have made participants more likely to use an intuitive approach to problem solving better suited for interpreting the intent of the robot. A lower Agreeableness would also make the participants less likely to refrain from opening the Microwave in case of concerns regarding social desirability.

The results related to Subscale 3 of the NARS as well as the two significant ad-hoc measures, suggest that participants who were more apprehensive about robots actually having emotions were more alert to the non-verbal cues given by the robot. Öhman and Mineka [22] suggest that fears and phobias give the sufferer an advantage in terms of attending to specific stimuli related to these fears. In addition, Syrdal et al. [23] found a relationship between higher scores on the NARS and the ability to distinguish between robot behaviors. It seems that the results described here show an analogous effect. Additionally, the results also indicate that people who observed the robot behaviors are more likely to understand its intention. Considering this aspect, we can argue that behaviors designed for the Sunflower robot proved to be effective in drawing the person's attention to the sound and leading them to the source. The link between success and intuitive thinking style suggests that they were successful by tapping into the modalities used by hearing dogs.

The participants' responses indicated that the most successful behaviors for communicating intent by the robot were related to its eye gaze and head actions. It follows therefore that the robot's head was an important focal point for the participants during their interaction. Similarly to human-human and human-dog interactions, gaze and eye contact also play important roles. Therefore, when designing robots for interaction, it is essential to create a focal point for the user through which the robot can express its intentions.

The responses also suggested that the dog-inspired Attention Seeking, Looking Back and Gaze Alternating behavior sequences were successful in helping the robot achieve its goal. Overall, we have shown that dog-human interaction has the potential of helping researchers and designers in designing a robot that is capable of utilizing visual communication signals to support human-robot interaction. This also allows for adding further modalities for communicating in addition to existing modalities (such as vocal dialogue or on-screen displays) in order to draw attention to, emphasize, or disambiguate information delivered through other channels.

Overall, the findings from this study indicate that 1) humans can attribute intentions to robots based solely on visual communication signals, 2) they can comprehend the robot behavior even if it was their first encounter and regardless of their background. Therefore, these encouraging results suggest that human dog interaction can be used as a source of inspiration for designing social behaviors for robots. Researchers interested in human-robot interaction should also consider exploring other human-animal interaction modalities as they may provide further inspiration for more useful or suitable visual communication and expressive signals for their robots in other contexts and situations.

V. FUTURE WORK

Findings from the work presented here will guide the continuing developments of visual communication signals for a companion robot prototype Care-O-bot® 3 [24] that is being used in the FP7 ACCOMPANY project [25]. This project focuses on the needs of an ageing population in which simple visual communication signals may be useful in dealing with late onset hearing impairments and for expressing empathic behaviors. Previous work has suggested that elderly people are accepting of animal-inspired cues [26], and our aim is to explore these possibilities systematically.

Visual communication signals will enhance interactions. For example, the robot may use its gaze to disambiguate intentions in situations where participants who are not familiar with technology may get confused (i.e. which cup the robot is referring to in a fetch-and-carry task, or which direction the robot is going to take when navigating around the home environment). Furthermore, the robot may use visual communication signals to express its internal state (such as 'busy', 'low power' etc.) or to encourage or warn users. Our future studies will investigate whether, with these cues being implemented, users will be able to understand the robot's state (e.g. 'free' or 'busy') easily and more intuitively, compared to having to resort to consulting the robot's user interface or an operation manual to interpret the status of the robot. This is hoped to facilitate the adoption of these types of technologies for potential users who are skeptical, or who get easily confused by technologies they are unfamiliar with.

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