A Simple Nod of the Head: The Effect of Minimal Robot Movements on Children's Perception of a Low-Anthropomorphic Robot

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ABSTRACT
In this note, we present minimal robot movements for robotic technology for children. Two types of minimal gaze movements were designed: *social-gaze movements* to communicate social engagement and *deictic-gaze movements* to communicate task-related referential information. In a two (social-gaze movements vs. none) by two (deictic-gaze movements vs. none) video-based study (*n*=72), we found that social-gaze movements significantly increased children's perception of animacy and likeability of the robot. Deictic-gaze and social-gaze movements significantly increased children's perception of helpfulness. Our findings show the compelling communicative power of social-gaze movements, and to a lesser extent deictic-gaze movements, and have implications for designers who want to achieve animacy, likeability and helpfulness with simple and easily implementable minimal robot movements. Our work contributes to human-robot interaction research and design by providing a first indication of the potential of minimal robot movements to communicate social engagement and helpful referential information to children.

ACM Classification Keywords
H.5.2. User Interfaces (e.g. HCI): Prototyping-User-centered design

Author Keywords
human-robot interaction design; non-anthropomorphic robot; children; nonverbal communication; robot behavior

INTRODUCTION AND RELATED WORK
In many classrooms, children's rooms and playgrounds, we are starting to find robotic products designed to interact with children. Research has shown that robots hold tremendous promise for children's education and socio-emotional development [8, 9, 12, 14, 17, 21, 29] paving the way not only for research, but also for consumer robots for children. While the application domains vary – from educational learning like the Dash and Dot Robots[1] to child therapy with the Leka Robot[2] – common attributes of these robotic products are simple aesthetics, minimal actuation, and nonverbal communication.

Robots designed for children that do not fall in the classic humanoid shape and that rely on nonverbal behavior have clear design advantages: (i) children's expectations of interaction [39] are minimized (e.g., a humanoid face might raise the expectation that the robot is able to understand and produce natural language which is often not the case [41]), (ii) robustness and reliability of the robotic system *in the wild* is maximized (e.g., robot-limb-based locomotion can be complex and is rarely reliable outside laboratory and industrial settings), and (iii) the Uncanny Valley effect is avoided [24, 35]. However, limiting the anthropomorphic robot appearance and reducing the range of communicative modalities available has the disadvantage of leaving interaction designers with fewer degrees of freedom to work with to design robot behaviors. Increasingly, a solution to this disadvantage is to carefully design nonverbal behavior that *'buys the designer valuable expressive power of which other aspects of the robot's design can be relieved'* [13].

Researchers have been exploring design solutions for nonverbal communication of low and non-anthropomorphic robots by focusing on body movements, gaze and other nonverbal behaviors. Body movements and locomotion enable low-anthropomorphic robots to communicate their intentions, internal states, and emotions, contributing to people's comprehension and acceptance of the robot [13, 18, 19]. The importance of a robot's *movements* has been shown by Takayama et al. [36], who demonstrated that by adding simple movements displaying forethought and reaction, the readability and fluency of human-robot interaction were increased. In a similar vein, Sirkin et al. [32] unveiled how robot movements alone are sufficient to convey intention and coordination of joint actions. Fink et al. [10] evaluated the interplay between reactive and proactive engagement-seeking movements, sounds and lights for a robotic toy box to motivate young children to tidy up their room. Interestingly, the proactive nonverbal behaviors were less effective than the reactive ones, distracting the children

[1]https://store.makewonder.com/
[2]https://www.indiegogo.com/projects/leka-an-exceptional-toy-for-exceptional-children-autism#/

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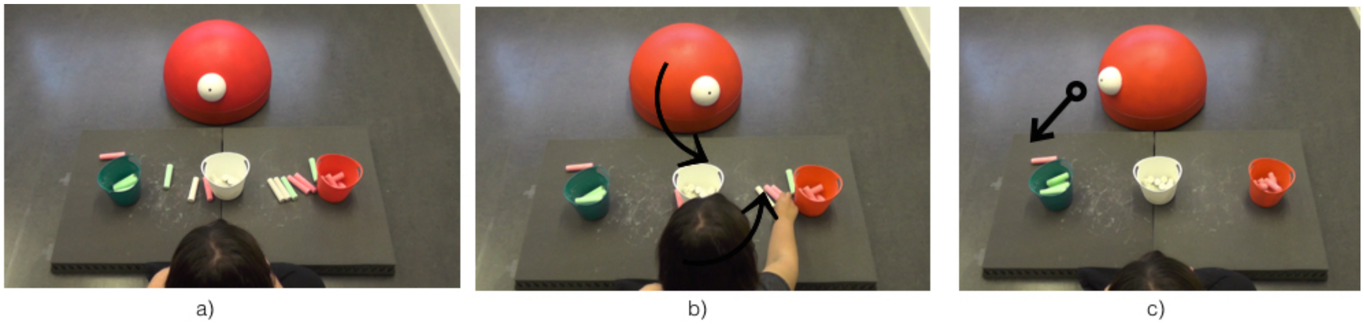

Figure 1. Figure a) the robot and the actor at the beginning of the sorting task; b) the robot exhibiting social-gaze movement towards the actor; c) the robot exhibiting deictic-gaze movement to provide helpful referential information.

from the tidying up activity. *Gaze* is a powerful nonverbal behavior that greatly supports human-agent interaction [2, 6, 11, 25]. Even though eye gaze and head gaze can be challenging to realize in robots without a clearly distinguishable head and actuated eyes, there is evidence that the communicative power of gaze can also be achieved in low-anthropomorphic robots. For example, results on the role of affiliative and referential gaze from literature on virtual agents [3] can be reproduced in non-humanoid robots. In fact, Lehmann et al. [20] showed that low-anthropomorphic robot's gaze-shift-like movements synchronized with a user's movements positively shaped the interaction in an object-oriented task.

However, two crucial open questions for interaction designers are *how* to design nonverbal robot behavior for low-anthropomorphic robots and what *effect* the robot's behavior will have on the user's perception of the robot. This holds particular importance in child-robot interactions (cHRI), as children bring unique challenges related to the attribution of agency and perception of interaction affordances [16, 37].

In our research, we address the challenge of designing appropriate nonverbal behavior for cHRI. We explore how a low-anthropomorphic robot can communicate social engagement and task-related referential information during a playful joint activity, thereby communicating as a life-like goal-directed agent, a prerequisite in these kind of interactions [27, 38]. The communication is achieved relying only on minimal movements of the robot's whole body (i.e., rotation of the base of the robot) which are simple, technologically not costly and easily implementable. To this end, we designed *social-gaze movements*, synchronous movements shifting toward the interaction partner. To provide helpful task-related referential information, we designed *deictic-gaze movements* shifting the robot's body orientation to an object of interest for the task.

We evaluated the legibility of the minimal movements and children's perception of animacy, likeability and helpfulness of the robot's behavior in a video-based study (VHRI). Animacy is one of the crucial features in children's robot perception [7, 26], as it is a prerequisite to attribute states and qualities to a robot and it maps onto concepts of agency and perceptual causality, which are key concepts in children's perception of agents [1, 26, 27]. Discerning how social-gaze movements and deictic-gaze movements affect children's perception of **animacy** is important to assess the viability of using minimal movements. We measured **likeability** of the robot because positive impressions (e.g., kind, friendly) are important aspects in robot design for children [4, 5]. We measured **helpfulness** since we want to know how our minimally designed social and deictic-gaze movements shape children's perception of helpfulness. Drawing from literature [3, 20], we expect that,
H1: Minimal robot movement resembling social gaze will increase children's perception of animacy (H1a) and likeability (H1b) of the robot.
H2: Minimal robot movement resembling deictic gaze will increase children's perception of helpfulness (H2a) of the robot, and will increase the effect of children's perception of social-gaze movements on animacy (H2b) and likeability (H2c) of the robot.

MINIMAL ROBOT MOVEMENTS: DESIGN AND EVALUATION METHOD

From a methodological perspective, our research follows a combination of human-robot interaction (HRI) design methodologies that has been shown to yields impactful findings [13, 31, 33] also with our population [26]. Our research focus is on designing minimal communicative robot movements during joint activities (e.g., playing together). Our approach is to evaluate our designs in video-based studies and follow-up with *in-person* and *in-situ* behavioral studies. In this note, we present our VHRI study, wherein we exposed children to videos of a robot's social-gaze and deictic-gaze movements to evaluate children's perceptions of animacy, likeability and helpfulness of the robot's behavior. To test our hypotheses, we conducted a two (social-gaze movements vs. none) by two (deictic-gaze movements vs. none) between-subjects video experiment. For each condition, we recorded a movie slightly over one minute in length. In the video, a female actor sits in front of a grey mat where colored chalks were (seemingly) randomly scattered next to three colored baskets (Figure 1a). The robot is positioned on the opposite side of the mat facing the actor and it was controlled remotely by another researcher. We chose the same camera perspective as [20], i.e., over-the-shoulder of the actor (only arms and back of the head visible) to minimize the 3rd person perspective [30]. We asked each participant to watch the movie and to respond to an online questionnaire on SurveyMonkey[3] administered via tablet computers.

[3] https://www.surveymonkey.com/

Robot, scenario and minimal movements design

The robot used is a Festo Robotino[4], a mobile robotic system with three omnidirectional wheels. The robot is covered with a low-fidelity Styrofoam semi-spherical shell. The only anthropomorphic element is a white sphere with a black dot that resembles an eye, not actuated. The robot only rotated (1 degree of freedom).

In our scenario, the robot interacted with an actor during a simple sorting task, i.e., sorting chalks by color. As the robot could not fully participate in the object manipulation task (it does not have arms or grippers), we framed its role as a reactive, but engaged co-player. The robot exhibited social engagement by attentively following the co-player's actions (i.e., social-gaze movements) and provided helpful referential information for the completion of the task (i.e., deictic gaze), by *'pointing'* at the location of the last missing chalk outside the co-player's field of vision.

The design of the robot's minimal movements is derived from virtual agents' and robot's gaze literature [3, 20] and follows principles of animacy [16, 27]. To design social-gaze and deictic-gaze movements, we used solely motion. The minimal robot movements consist of lateral shifts of its base, adapted to the degree of freedom of the robot. The resulting robot behaviors included whole-body (i.e., robot base) shifts (right or left) within an angle of 30 degrees to maximum 120 degrees. Social-gaze movements are devised as robot base shifts aligned to the actor and following face and body orientation of the actor throughout the task (i.e., looking where the actor is looking). The social-gaze shifts start with a minimal latency when the actor moves her head or arm. They are timed to be positively synchronous and they are contingent on the actor's actions (i.e., robot follows the movements and actions of the actor, generating the impression of being socially engaged). Deictic-gaze movements are devised as robot base shifts oriented towards an object. In our case, the robot points once towards the last chalk at the end of each sorting task session (Figure 1b, 1c).

Participants

The study was conducted with 72 participants recruited among 4 classes coming from international elementary schools in Manchester (UK) and Hengelo (NL), where the language of instruction is English. Their age ranged between 8 and 12 years (M = 9.63, SD = .95, $Median$ = 10); 55.6% of the participants were female (N = 40, M = 9.75, SD = .92, $Median$ = 10) and 44.4% was male (N = 32, M = 9.47, SD = .98, $Median$ = 9). 81% of the participants had seen a robot in real life before and 55.6% reported to have played at least once with a robot.

Independent variables

We manipulated social-gaze movements and deictic-gaze movements of the robot between subjects. The resulting conditions are: (i) *social and deictic-gaze movements condition* (i.e., the robot exhibited social-gaze movements since the beginning of the sorting task and the deictic-gaze movements only to indicate where the missing chalk is); (ii) *social-gaze movements condition* (i.e., the robot exhibited social-gaze movements from the beginning of the sorting task and does not exhibit deictic-gaze movements to indicate the missing chalk); (iii) *deictic-gaze movements condition* (i.e., the robot only *'pointed'* at the missing chalk) and (iv) *static condition* (i.e., no social nor deictic-gaze movements).

[4]http://www.festo-didactic.com/int-en/services/robotino/

Manipulation and legibility check

To check the manipulation of social-gaze and deictic-gaze movements a single multiple choice item (i.e., a factual question about how the children understood the robot's behavior) was inserted. This question also allowed us to assess the legibility of the robot's behavior in the scenario. The item was: *What do you think the robot was doing? a) The robot was only pointing at the missing chalk, b) The robot was following what the person was doing and pointing at the missing chalk, c) The robot was standing still doing nothing with the person, d) The robot was only following what the person was doing*. The manipulation was successful and the legibility of the robot's behavior satisfactory. Participants were able to correctly recognize the actions underlying the robot's minimal gaze movements above chance ($\chi^2(d = 9) = 145.166$, $p < .001$).

Dependent variables

We measured perception of animacy and likeability with three items for each construct (both constructs reach high reliability, Cronbach's alpha animacy = .77, and likeability = .88) of the corresponding dimension of the Godspeed questionnaire [4], an HRI validated measure of participants' perceptions in a semantic scale. We designed a 5-point Smiley-o-meter [28] scale item like [22] (*How helpful do you think the robot was*) anchored from *Not helpful at all* to *Very Helpful* to assess the perception of helpfulness of the robot.

Setup and procedure

Participants received a brief introduction, thereafter they were randomly assigned to one of four experimental conditions, which resulted in sub-sample sizes of n = 17 for social and deictic-gaze movements, n = 19 for social-gaze movements, n = 19 for deictic-gaze movements, and n = 17 for the static condition. Each participant sat at a table equipped with a tablet, i.e., Apple iPad, with the browser open on the questionnaire page. An activity facilitator was instructed to support the participants in case of problems and to debrief them upon completion of the questionnaire.

RESULTS AND DISCUSSION

A two-way analysis of variance (ANOVA) was conducted to evaluate the effects of social-gaze and deictic-gaze movements on children's perception of animacy, likeability and helpfulness of the robot.

Perception of animacy

The results of perception of animacy of the robot support H1a, but they partially support H2b. We found an interaction effect of social and deictic-gaze movements on the perceived animacy of the robot ($F(1,68)$ = 7.168, p = .009, η^2 = .005). Simple effect analysis of social-gaze movements shows that social-gaze movements play a great role in the perception of the robot as '*life-like*' and '*socially engaged*'. Social-gaze movements significantly ($F(1,58)$, $p < .001, \eta^2 = .042$) contribute to the perception of animacy both in combination with deictic-gaze movements ($M = 3.75$, $SD = 0.68$) or not ($M = 3.68$, $SD = 0.64$). However, simple effect analysis of deictic-gaze movements show that they do not play a significant role in the perception of animacy (i.e., no significant difference).

Perception of likeability

The results for perceived likeability support H1b, but not H2c. We found no interaction effect of social-gaze and deictic-gaze movements on perceived likeability of the robot. We found that social-gaze movements ($F(1,68) = 4.847$, $p = .031$, $\eta^2 = .06$) had a main effect on the perceived likeability of the robot, which significantly increased (social gaze: $M = 4.17$, $CI[3.922 - 4.409]$; no social gaze: $M = 3.79$, $CI[3.542 - 4.029]$), while deictic-gaze movement did not have an effect on likeability, even though deictic-gaze movements were expected to contribute to the perception of likeability by delivering referential information in the task.

Perception of Helpfulness

The results of perceived helpfulness support H2a, but present an additional result. We found no interaction effect of social-gaze and deictic-gaze movements on perceived helpfulness. From main effect analysis though, deictic-gaze movements (hypothesized) and social-gaze movements (not hypothesized) both had a main effect and increased the perception of helpfulness of the robot (social gaze; $F(1) = 43.811$, $p < .000$, $\eta^2 = .33$ no deictic gaze: $M = 2.90, CI[2.637 - 3.156]$, deictic gaze: $M = 4.12, CI[3.855 - 4.374]$, deictic gaze; ($F(1) = 5.427$, $p = .023$, $\eta^2 = .004$ no social gaze: $M = 3.29$, $CI[3.031 - 3.551]$, social gaze: $M = 3.72$, $CI[3.406 - 3.908]$). From pairwise comparison and estimates analysis, we found that deictic-gaze movements are fundamental to perceive the robot as helpful, but it is when deictic-gaze and social-gaze movements are combined that perceived helpfulness increases the most (i.e., yields the highest rating for perceived helpfulness, $M = 4.12$, $CI[3.855 - 4.374]$).

CONCLUSION, LIMITATIONS AND FUTURE WORK

In this note, we explored the design of minimal robot movements resembling social and deictic gaze and we evaluated how they affect children's perception of animacy, likeability and helpfulness of the robot's behavior. We show that minimal robot social-gaze movements and deictic-gaze movements communicate social engagement and helpful referential information and affect children's perception of animacy, likeability and helpfulness. Specifically, we found that the perception of animacy and likeability significantly increases with social-gaze movements, but not with deictic-gaze movements. Although perception of helpfulness significantly increases with deictic-gaze movements, it is when both deictic and social-gaze movements are used that perceived helpfulness increases the most. Our results are relevant for interaction design and have design implications. In particular, social-gaze movements deliver social engagement in a task and have a compelling communicative power. They can be employed, alone or in combination with other minimal movements (in our case, deictic gaze), to achieve animacy and influence likeability of the robot. These movements potentially enable a set of easily implementable robot behaviors for low-anthropomorphic robots. Deictic-gaze movements deliver task-related referential information and affect the perception of helpfulness, but to reach the maximum effect on perception of helpfulness, designers should combine social and deictic-gaze movements. Moreover these findings lay the ground for *in-person* follow-up studies. Building upon our results, we will hone in to understand children's behavioral responses to social-gaze and deictic-gaze movements. Although adopting a VHRI method might pose some limitations (e.g., ecological validity and reliability of the results) [34], a large number of studies have shown that VHRI studies yield similar results as live HRI [20, 26, 33, 36, 40]. We chose a methodology that allowed us to address our hypotheses in a more controlled way. VHRI guaranteed uniformity of the stimuli and we can be relatively certain that the effects obtained are caused by our experimental variables and not by contextual factors, resulting in high internal validity. In addition, VHRI allowed us to reach a relatively large sample size, which is uncommon in cHRI [5]. Another potential drawback of the adopted VHRI is that participants did not experience a live robot, but a video from a 3rd person perspective [30]. Despite the fact that 3rd person and indirect interaction appear to yield reliable results in cHRI [26], we carefully mitigated 3rd person perspective drawbacks by using an over-the-shoulder camera view: participants were able to focus on the robot, not distracted by contextual information (e.g., actor's age, gender or ethnicity). This was also expected to address the limited immersiveness [15] of VHRI. We focused the scope of our VHRI study to our robot platform, but it is possible that our minimal movements can be adapted to other platforms by virtue of their practicality and simplicity for robot design. We focused on children, however, we imagine that adults could also respond to minimal robot movements in a similar manner, by virtue of the simplicity of the movements. We leave empirical evaluation of this as future work. Despite the fact that VHRI normally allows researchers to examine large design spaces with many variables, we investigated only a limited set of variables and measures that were instrumental to our investigation. We believe that this adds to a higher reliability of children's responses, as for children it is often hard to understand and differentiate between too many constructs [23].

To conclude, our work contributes to HRI and design literature by showing the potential of minimal robot movements to communicate social engagement and helpful referential information. In particular, social-gaze movements and to a lesser extent deictic-gaze movements, have compelling communicative power, positively affecting children's perception of animacy, likeability and contributing to the perception of helpfulness of the robot. Our results will strengthen future *in-situ* evaluations and *in-person* studies.

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