Social Robotics
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It was a Pleasure Meeting You

Towards a Holistic Model of Human-Robot Encounters

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Abstract Social signals are commonly used to facilitate the usability of humanoid robots. While providing the robot with an extended expressibility, these signals are often applied only in structured interactions where parts of the familiarization or farewell processes are disregarded in the evaluation. In order to establish the consideration of a more comprehensive view, this article presents a holistic model of human encounters with a social robot. We propose and discuss particular robot signals, which aim to express the robot's social awareness, for each of the model's phases. We present an interaction study with humans that are inexperienced in interacting with robots to investigate the effects of these signals. Results verify that the implementation of proposed signals is beneficial for the participants' user experience. The study further reveals a strong interdependency of a robot's social signals and the importance of addressing entire encounters in human-robot interaction studies.

Fig. 1: A social robot acting as a receptionist in the foyer of a research building.

1 Introduction

Personal and domestic robots are becoming more commonly available which leads to a rapid increase in research on social robotics [42]. At the same time, according to [64], particularly highly autonomous robot systems can be difficult to comprehend for a human if they only exhibit a low amount of transparency regarding their decision making. As a possible approach to solving this discrepancy, already [60] names the provision of humans with models of machines and vice versa as one of the central challenges in social robotics. An appropriate mental model of such a robot is thereby believed to facilitate an interaction [16], for example by decreasing the mental workload [10].

In human interactions, nonverbal behaviours assist spoken language in building up adequate representations. [47] report that one of the most basic functions of nonverbal behaviours consists of providing the interactants with additional information. Such nonverbal behaviours can, for example, support turn-taking in a dialogue or help to establish interpersonal relationships by fulfilling a socio-emotional function [3]. Therefore, humans in parallel to speech employ nonverbal communication in their daily interactions as presented by [31] in a compre-

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hensive overview. As a reasonable consequence, [7] find an efficient way to raise the robustness of an interaction between human and robot in providing the robot with nonverbal signals. Social functions are further known to help disambiguate attitudes in human interactions [41]. When applied to robots, they are also frequently intended to reveal the robot's current state to a user so that its actions are more comprehensible [11] and possible confusions are minimized. As a consequence, the expression of nonverbal social signals can enrich a human's mental models about their robot interlocutor. [35] also elaborate on a variety of studies with robots that suggest further long-term benefits of social behaviours on the interaction.

On the contrary, social signals, such as a robot's movement characteristic can also negatively influence a user if not concerted carefully with the robot's appearance [9]. Other robot behaviours (for example, systemic recovery behaviours) can also have a social effect and harm the user experience [59]. Similar to animal and human interactions [63], the effectiveness of nonverbal social behaviours seems to depend on whether the robot provides meaningful signals [22] that match the receivers' expectations [38].

With this work, we intend to investigate meaningful ways to support the human in constructing appropriate models of how the robot functions during an interaction. An initial mental model of what to expect of the robot is already present in the human before the first contact and continues to evolve further. We therefore propose that an interaction between human and robot has to be regarded as embedded in an entire encounter from before mutual awareness until afterwards. A humanoid robot's nonverbal behaviour thus has to be modelled in an integrated way that covers the whole situation to support more robust interactions effectively.

For that purpose, we present a portfolio of nonverbal signals for a social robot that is targeted to reveal the robot's sociability and to facilitate a continued interaction. The portfolio particularly considers the social meaning of spatial configurations in distant interaction (*proxemics* [20]) and in close interaction (*f-formations* [28]). It is therefore well suited to cover an entire encounter between a human and a social robot. In a user study with inexperienced participants interacting with a receptionist robot (cf. Fig. 1), the suggested behaviours are validated with regard to their effects on the overall user experience as well as on subsequent phases of the interaction.

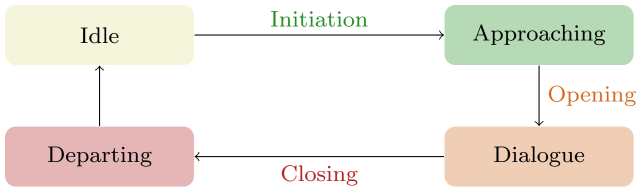

Fig. 2: Sequence diagram of two persons engaging and disengaging in a dialogue. The different stages (depicted in bubbles) are triggered by specific signals.

2 Modelling Human-Robot Encounters

A typical interaction as depicted in Figure 2 is rooted in a situation where two persons are yet unaware of each other. There is a certain distance between them, and they are possibly not in the same room. We refer to such a configuration as the *idle* stage. The approaching phase is induced when both notice each other and initiation signals are sent. During the *approaching* phase, one or both partners shorten the distance between them until a comfortable communication distance is reached [19]. At this moment, the conversation is *opened* with the first words being spoken. Usually, one of the interactants starts with a greeting phrase which is answered by the other one. Such a categorization of mutual engagement roughly resembles the suggestion of [29, Pg. 202], who describes greetings of arrivals at a garden party to generally include "a pre-phase of sighting and announcement, a distance salutation, an approach phase and a close salutation". Afterwards, the actual *dialogue* phase begins. The conversation is eventually *closed* with farewell words by both partners. Finally, both partners disengage and enter the *departing* phase where their distance increases as either one of them or both are leaving. After a successful disengagement, both arrive in the *idle* phase again without further signalling.

2.1 Communicating human awareness

As motivated in the introduction, the robustness of a robotic system can be improved if it is equipped with meaningful social signals that conform to user expectations. Gazing towards an object or human, for example, can lead to a better understanding of the robot by enriching the human's mental model about the robot's current focus of attention [5].

Already [15] have shown that reasonably coordinated strategies which are based on knowledge about the current spatial configuration can improve an interaction between a human and a robot. With our work, we particularly address an entire encounter that covers far and close interaction and therefore the social meaning of spatial configurations between the human and robot (cf. [37]) is also providing the basis for our behaviour portfolio.

Accordingly, we claim that with the additional provision of subtle hints (signals) that reveal the robot's interactive capabilities during and between each interaction stage (cf. Fig. 2), ambiguities and insecurities can be reduced when encountering a social robot. In other words, the primary hypothesis in this work can be stated as follows:

Hypothesis 1 *Well-concerted social signals can guide a person through an entire encounter with an interactive robot by fostering an understanding of the robot's capabilities which then leads to an enhanced user experience.*

To effectively support the human in the interaction, such strategies have to be appropriate to the current situation and not interfere with other behaviours. Additionally, each signal affects subsequent parts of the interaction which requires them to be adjusted to each other. We therefore designed behaviours that aim to help the robot to be perceived as (more) sociable and reveal the robot's inner state with regard to the current interaction stage. More specifically, the following criteria serve as a design guideline:

- Signals should facilitate the development of the human's mental model of the robot by aligning them to constructs in the human [41,6,66].
- Signals should convey information believably and consistently [63,22,62].
- Signals should meet the user's expectations with regard to appearance and task [38,12].

As a consequence, strategies that are presented next embody minimal, subtle, and nonverbal signals that aim to be human-like and therefore naturally understood by an interaction partner. They intend to positively influence the quality of an interaction as well as the perceived properties of the robot during a communication with a human interlocutor.

The remainder of this paper describes a proposal of interaction strategies for a social robot aimed at enhancing communication with a human partner. The introduced strategies contribute to the hypothesis by addressing every phase of the entire interaction situation coherently as depicted in Figure 2. In the following, they are presented as individual claims in order of occurrence during a dyadic encounter of human and robot.

2.2 Integrated interaction opening

People can have difficulties to realise that a robot is ready for an interaction, especially if it does not move at all [4]. As a consequence, [57] discuss social robot behaviours for initiating an interaction with humans by approaching them actively. In this work, we focus on the effects of certain nonverbal signals and therefore investigate a scenario where a human approaches a stationary robot, effectively factoring out the robot's movement characteristics. We likewise claim that entering a face-to-face dialogue between human and robot can be made more convenient by explicitly addressing the key signals of initiation and interaction opening that are used in human interactions.

According to [29, Pg. 165], there is a multitude of ways to initiate an interaction between humans from afar but a common point of origin among them is the identification of an individual as the person to get in touch with [45]. In a similar social greeting design, [21] describe an emphasized distant salutation for initiating human-robot interaction, which involves whole-body movements and waving gestures. Such a distant salutation is primarily employed between somewhat familiar people [29]. Contrarily, we claim that in human-robot encounters, and especially with a stationary robot of larger size, a more subtle distant salutation leads to a better user experience. Moreover, [52] find that a *contingent* way of initiating an interaction between a human and a robot is having a distinct positive effect on a later conversation.

A short and unobtrusive non-verbal initiation signal thereby similarly aims to draw attention to the robot in order to invite the human into the approaching stage. It reduces a humans uncertainty whether the robot is turned on or off, as well as communicating the ability and willingness of the robot to interact. As a consequence, we claim that the following interaction strategy can support an integrated opening of a dialogue from the first contact:

Claim 1 **(Initiation)** *Signaling the robot's availability from afar can lead from idling into noticing each other and an approaching behaviour.*

As reported by [29] as well as [45], a key signal prior to approaching is the establishment of mutual eye-contact. Subsequently, a short precise gaze towards the human is being proposed as the initiation signal. According to [27], such a gaze represents a subtle but effective way to signal availability while at the same time is appealing to the human counterpart. Besides clearly signalling that the robot is switched on, a short gaze also reveals functionalities of the robot [47] such

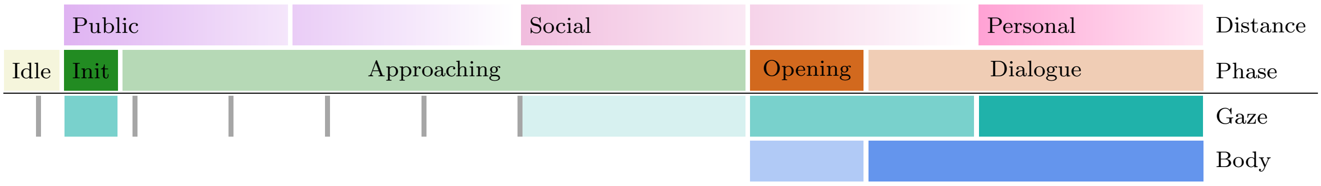

Fig. 3: Schematic depiction of the integrated attentive behaviour leading into a dialogue with a social robot. In the top row, the distance class between robot and human according to [20] is given. The second row describes the current phase or signal of the encounter (cf. Fig. 2). The bottom rows describe robot behaviour, i.e. rising attention towards the human with gaze (shades of cyan) interrupted by random gazes (grey) as well as via body orientation (shades of blue).

as its basic attention mechanism, namely head and eye movements, as well as the capability to recognize a human interlocutor. In consequence, it proposes the robot as a qualified interaction partner but does not force the user into a reaction as opposed to e.g. a more aggressive hand waving.

[21] model the approaching stage with phasing down robot involvement and avoiding eye-contact entirely, which gives the human intimacy [1] and thereby the option to abort the approaching behaviour without the social consequences of leaving the interaction one-sidedly. At the same time, the description of human greeting by [29, Chap. 6] as well as the formal notation of social distances by [20] allow for the conclusion that approaching each other consists of a gradual process of mutual involvement. Similarly, [23, 13] argue for continuous monitoring of the approaching human which allows for a distance-dependent incrementation of robot attention towards the human. Such behaviour is found to encourage further approaching behaviours while leaving it open for the human to pass on. During the approaching, the robot is not staring at the human continuously but also exhibits gazes to random targets to grant an appropriate amount of intimacy and indicate a cognitive readiness for other tasks [1]. The human is assured to be noticed by the robot and is also slowly familiarized with movement patterns of the robot. We therefore address the approaching stage in this work with the following claim:

Claim 2 (**Approaching**) *Gradually attending a human leads into a seamless transition from distant to close-up interaction.*

In exhibit increasing amounts of attention towards the human the approach implemented in [23] is being proposed. No further actions besides occasional random gaze shifts should be performed by the robot until the person decides to enter the social distance. Upon arriving in the social distance the robot should begin to focus a possible interaction partner with its head and eyes to indicate the readiness for a face-to-face interaction while occasionally gazing somewhere else [28] practising a simplified form of gaze avoidance [1].

The now imminent dialogue opening underlies many factors in human interaction, such as interaction history, social status and according to [58], in general, is a complex process. Pro-active robot behaviours [39] have been shown to guide a user through face-to-face interaction, so it is assumed to have a similar effect for opening [53]. We thus propose a self-initiated greeting at a proper communication distance (social *proximity* [19]) to expose the robot's verbal capabilities and also acts as an obvious entry point for the dialogue phase:

Claim 3 (**Opening**) *Pro-active robot greeting at a socially appropriate distance effectively opens up a dialogue.*

Similar to the close salutation described by [21] we accompany the greeting with a change in robot orientation to indicate the emergence of an interaction space (as in *f-formation* [29, Chap. 7]) preparing for the dialogue. Our suggestion here is to decouple body movements from speech but make them distance dependent. The robot should turn the torso half-way towards the person already when they enter the close social zone to create a new spatial configuration that prepares for greeting utterance and the dialogue. Now we consider two alternative ways of dialogue opening. Either the human utters a greeting phrase and the robot replies or the robot will pro-actively greet the human. In both cases, the robot would with the salutation engage in an f-formation with the human by visibly presenting its hands in front of its belly and leaning slightly forwards.

In summary, the first three claims represent a portfolio of nonverbal social behaviours for leading into a dialogue between human and robot. Figure 3 schematically depicts the here suggested behavioural enhancements. During the *idle* and *approaching* phases, the robot regularly changes the direction of its gaze towards

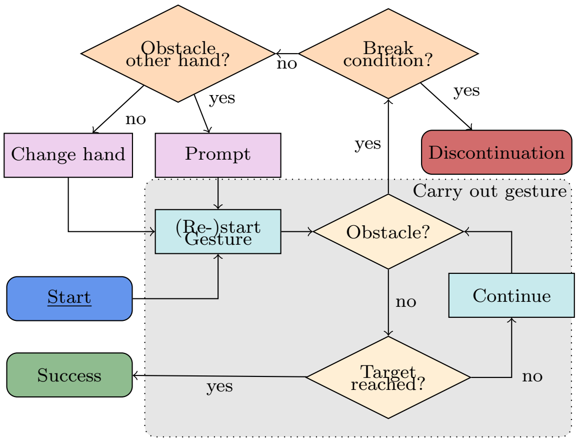

Fig. 4: Flowchart of a pointing gesture involving a spatial prompting mechanism. To reach its goal, the robot checks whether a potentially occupied area can be made accessible with the help of social signals to reach its goal. The gesture is only aborted if a defined exit condition is fulfilled.

a randomly selected target to signal availability even if no possible interaction partner has yet been detected. During the dialogue, arguably gaze does not need to be artificially distracted as attention has to be divided anyways between human and the current focus of the robot's task.

Upon recognizing a person, the robot sends out an *initiation* signal with the intention to lead into an approaching behaviour. A short gaze is sent instantly, i.e. also at far distances. Only if a human arrives in a socially interactive distance, the robot begins to continuously focus its possible interaction partner with its head and eyes. As soon as the human enters a close social zone, also the hip is being integrated to turn the torso slightly towards the person creating a new spatial configuration for opening up the interaction. The robot then also uses a verbal utterance to lead over into the dialogue phase.

In an interactive setting, the human usually enters the far phase of the personal distance shortly after the dialogue begins. Such a distance is comfortable for an interaction with the robot due to an establishment of a vis-a-vis formation resulting in a common interaction space. To maintain such an f-formation robot-wise, the robot uses its full potential of hip, head, and eyes for displaying attention towards the human in personal distance.

2.3 Guiding through conversation

Human dialogue is accompanied by iconic and lexical gestures [30] that contribute to the robustness of the conveyed information, for example by supporting turn-taking [3]. Moreover, complementary motions, as proposed by e.g. [26], can provide additional benefits for an interaction between humans and robots and help with the creation of appropriate mental models [55].

We claim that gestures cannot be treated independently from spatial configurations in the interaction space, as e.g. the positioning of objects and social presence of humans are expected to influence the robot's behaviour [24]. Therefore, we assume that *spatial prompting* as introduced by [17] and [50] can be used as an appropriate method to induce a human to retreat their hands from areas of interest for the robot. With a prompt, the onset of a gesture is carried out indicating the desire to move into that direction, similar to how people signal a change in their walking direction if they are on a collision course with another person.

Such an approach constitutes an acceptable compromise between discontinuation or immediate abandonment of the gesture on the one hand and carrying on regardless on the other hand. We expect to be able to solve territorial conflicts between human and robot using spatial prompting without the need to cancel a task while leading to a better understanding of robot capabilities and demands in the human.

In summary, the following strategies are believed to enhance a robot's multi-modal dialogue by providing additional information about the robot's awareness of a human's social presence in the interaction space.

Claim 4 (Dialogue) *Supporting pointing gestures and spatial prompting can help to resolve ambiguities and conflicts in the interaction space.*

Figure 4 depicts a proposal for implementing spatial prompting into an interactive robot dialogue. As long as a gesture is carried out, the system monitors the active peripersonal space for obstacles that are caused by human presence. If an obstacle blocks the way towards the desired target or the target itself, the robot might explore strategies that aim to reach the target in a socially aware manner. At first, the system should check whether the target might be reachable through an alternate route, using the other hand. If the robot is not successful, a multi-modal signal can be employed in order to suggest a pointing intent towards the location and motivate the human to recede from the area of interest. This signal involves a brief utterance, e.g. "This…", a predictive gaze towards the target (cf. [5]), and an indicated gesture. Only after several unsuccessful attempts, the robot should abandon its effort.

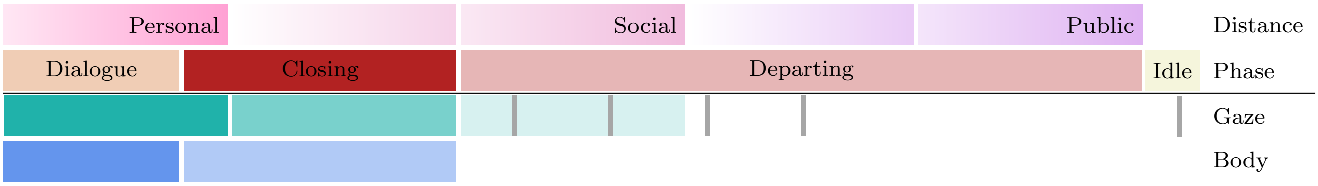

Fig. 5: Schematic depiction of the integrated attentive behaviour phasing out the interaction with a social robot. In the top row, the distance class between robot and human according to [20] is given. The second row describes the current phase or signal of the encounter (cf. Fig. 2). The bottom rows describe robot behaviour, i.e. decreasing attention towards the human with gaze (shades of cyan) interrupted by random gazes (grey) as well as via body orientation (shades of blue).

2.4 Closing interaction

To address the user experience in an entire encounter with a social robot the interaction ending has to be considered as well. Surprisingly, very few HRI experiments address interaction closing explicitly. [54] observe premature and sudden disengagements with a social robot in a game interaction. Especially because robots sometimes reply slowly [61], confusion could emerge whether there is more information being provided or the utterance is over [32]. We therefore consider an explicit closing of the interaction as well as actively leading into a departing phase to be beneficial in terms of user experience.

Similar to the opening of a dialogue the exact moment when an interaction with a robot is coming to an end is not always clear. Mixed-initiative strategies (for example, presented by [49]) have been shown to require less clarification and therefore also qualify as a method to close the dialogue appropriately.

Claim 5 (**Closing**) *Mixed-initiative farewell strategies effectively close a dialogue between human and robot.*

We propose to offer two ways of closing the dialogue. The first method is to actively end the interaction with an utterance if either the ending can be assumed by the robot or the human does not talk for a certain amount of time. As an alternative, the human is also able to terminate the dialogue at any time by saying good-bye and the robot will reply with a farewell utterance.

Actively signalling disengagement after the dialogue has been closed further clarifies the end of an interaction and leads to mutual disengagement. Such behaviour is believed to also finalize the current interaction [14]. At the same time, the robot is still perceived as switched on and ready for a re-engagement.

Claim 6 (**Departing**) *Signaling robot standby behaviour leads to the human disengaging and departing the robot.*

In the *departing* phase, we propose a gradually decreasing involvement as depicted in Figure 5. We suggest starting the departing by breaking up the *f-formation* with the robot moving its body back to its normal orientation facing forwards and placing the hands next to its hip oriented downwards. While the human is departing, the robot should then exhibit a decreased amount of attention by gradually reducing head and eye-movements. The resulting robot behaviour is complementary to the behaviour exhibited during the human's *approaching* (cf. Section 2.2).

3 Experimental Evaluation

We have conducted an experiment that aims to investigate the proposed nonverbal behaviours in terms of their effects on user experience. People that are mostly unfamiliar with robotics participated in an interaction with a semi-autonomous social robot in a receptionist scenario. The iCub [43] robot has been employed for the evaluation because it has a humanoid appearance which is well accepted by humans [2] and fits its role. It is also equipped with a wide range of interactive capabilities, i.e. movable torso, head, eyes, and arms including hands and fingers. In contrast to other experiments that investigate mutual approaching [57], the robot in our experiment is set up as a stationary receptionist and functions as described in [25] to limit its action space and thereby reduce the complexity of spatial configurations between human and robot. Similar settings (cf. Fig. 1) appear to be well established to research effects in human-robot interactions such as the robot's social properties [34] and politeness [56], homophily with a human [40], and their literacy [65] or emotions [51]. It is also well suited for researching spatial engagements [44] and can cover an entire encounter as discussed in Section 2.

3.1 Group design

The experiment is set up to manipulate the robot's behaviour in three independent variables as a 2x3x3 between-group design[1]. All participants are randomly assigned to one of the conditions in each of the variables to interact once with the robot without any repetitions. As a result, every participant experiences a robot behaviour that emerges from the combination of one of two initiation conditions, one of three different opening styles, and one of three different prompting strategies.

The first variable modulates whether participants either experience a very distinct and therefore *Strong* initiation signal with the robot gaze directed straight towards their face when they enter the experiment room or a *Weak*er signal, where the robot only turns 50% of the way before moving back to idling behaviour. In both cases, however, only head and eye movements are employed. With the help of this modulation, it is aimed to draw conclusions about the style and impact of the initiation signal (Claim 1) that leads from idling into the approaching phase.

A second independent variable parameterizes the now following approaching phase (Claim 2) and opening signal (Claim 3) together. As suggested by [23], the control group experiences *Random*-only eye and head movements as a baseline indicating that the robot is active while they are inside the room. The integrated opening behaviour as depicted in Figure 3 and described on Page 4 ff. is exhibited only in the *Full* condition. To evaluate the importance of (missing) pro-active opening strategies, the same full dynamic opening but with a much *Delayed* robot greeting, seven seconds after the participant enters the close social distance is investigated using a third participant group. A gaze controlling mechanism implemented by [46], which implements human-like head-eye coordination [18], is used in all three conditions.

During dialogue itself, a third independent variable is employed to research the effect of spatial prompting strategies for conflict solving (cf. Claim 4 in Section 2.3). In the control group, the robot does not emit a pointing gesture at all towards the floor plan during the explanation. Instead, it solely explains the way using real-world coordinates. All other groups experience robot gestures towards the floor plan, while their obstruction strategies vary. In the simple condition, possible interferences cause immediate cancellation of the gesture which represents a baseline behaviour. Social signals are only incorporated if the floor-plan is obstructed in interactions of the prompting group.

[1] Please note that participants experienced four different expressions of the third variable as explained in the text.

Table 1: Participant breakdown for the different experimental conditions

(a) Initiation

Condition	#
Weak	31
Strong	43
	74

(b) Opening

Condition	#
Random	37
Full	20
Delayed	17
	74

(c) Prompting

Condition	#
None	28
Regular	28
Give-up	18
Prompting	16
	90

As a direct consequence from this arrangement, the robot behaviour varies in four different ways: (i) the robot does not exhibit a gesture towards the floor plan (*None* condition); (ii) the gesture is carried out *Regular*ly without any conflicts; (iii) the robot has to *Give up* a gesture attempt; or (iv) a *Prompting* strategy is employed to reach the position. This set of trials has been determined by analysing the interaction logs and verified using annotations for occurrences of a gesture being interrupted by the participant.

3.2 Participants

In total, 105 people have all consented and participated in the study. They have received five Euros as compensation for their efforts. 15 trials have been excluded from the evaluation because the participant either has not followed instructions or they have experienced a faulty setup caused by erroneous configurations or operator controls. Of the remaining 90 participants, 46 are female and 44 male. Their age ranges from 19 to 50 ($\bar{x} \approx 26.1$, $\sigma \approx 6.5$) with an average self-assessed German knowledge of $\bar{x} \approx 3.9$ ($\sigma \approx 0.1$) on a (0-4) Likert scale [36] and only a single rating below maximum. As the recruiting has taken place on campus for the most part, many participants are either students (78%) or academics (7%). Of the students, approximately 27% are enrolled in a subject related to natural or technical sciences. On a (0-4) scale, the participants' computer knowledge is solid with an average of $\bar{x} \approx 2.71$ ($\sigma \approx 0.84$), while in general, they are relatively unfamiliar with robots other than those from movies as they rate their knowledge with $\bar{x} \approx 1.38$ ($\sigma \approx 1.18$) on average.

The first 16 participants of the study used a headset microphone to communicate with the robot during the experiment. Such a setup arguably alters the perceived social distance to the robot as participants are able to talk with it from afar. Moreover, these participants have not experienced the closing strategy described in Section 2.4. Consequently, the only 74 participants are analysed in terms of interaction initiation and opening but the first 16 participants are explicitly addressed in terms of interaction closing in Section 4.4. We have also removed the microphone from subsequent trials. A final participant breakdown into the experimental conditions is given in Table 1.

3.3 Setup

In order to conduct a study that considers a holistic interaction and spatial configurations, the study has to be located in a room of appropriate size to cover a complete encounter in its full spatial extent. Participants may not come into contact with the robot prior to the study to prevent side effects of early appreciation or even familiarity. The participant briefing and debriefing therefore have to happen in a room next to the robot.

Consequently, the location for conducting the user study is set up as depicted in Figure 6. The experiment room to the left can be entered through an always open interconnecting door so that participant briefing can take place in the room to the right. Inside the experiment room, there is a large empty space in the centre as well as the iCub opposite to the designated entry point. Participants have to approach the robot from afar so that different strategies during pre-dialogue phases can be explored. The social distance between the robot and human at the entrance spans up until the beginnings of the far public class (cf. [20]) so that all relevant segments have to be passed before engaging in a face-to-face interaction. At the beginning of the experiment, the robot is not yet oriented towards the door, so that it is forced to turn in order to redirect its attention towards a possible interaction partner and open an interactive f-formation (cf. [29]). A floor plan is placed on a small desk directly in front of the iCub to allow for gestural interaction in a way finding task as depicted in Figure 7.

An RGBD-camera is employed at 175cm height behind the robot with to recognise human faces and positions while approaching as well as to register hand activities on the desk. Due to the limited range and resolution of the first camera, a secondary camera is used to detect participants as soon as they enter the experiment room through the interconnecting door. It remains hidden on a desk between other hardware and acts as a detector to trigger the initiation signal. Behind a visual cover, there is a workspace for the investigator in close proximity to the robot where it is possible to observe the robot and stop it immediately in an emergency case.

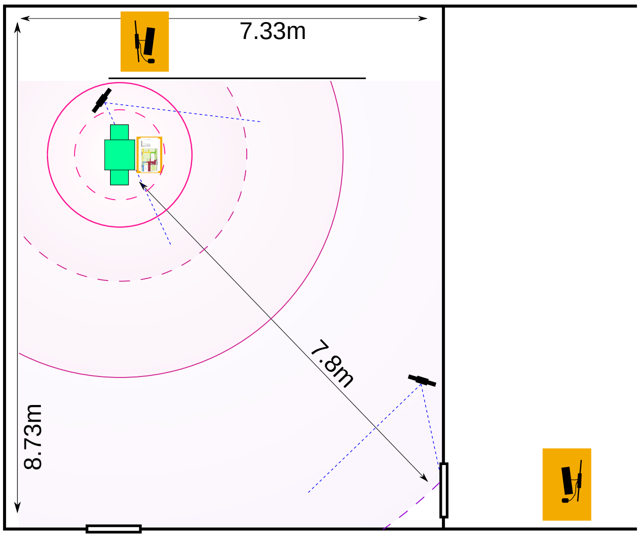

Fig. 6: Schematic depiction of the physical arrangement during the user study from above. The experiment room to the left contains the receptionist setup, two cameras, as well as the hidden investigator desk. In the second room, there is a workplace for participants of the study. Social distance classes [20] are given as bubbles around the robot.

3.4 Procedure

Immediately upon arriving, participants are asked to take a seat at the computer inside the room to the right where they are yet unable to perceive the robot. They then have read the introduction which familiarizes them with the purpose and nature of the study. People could continue to participate in the study after giving their consent for using their data, including personal information such as videos, for scientific purposes. During the briefing, they are introduced to the task and instructed how to interact with the live robot system in terms of robot capabilities regarding speech and gesture. Participants were in particular informed that the robot can understand simple statements in English as well as (pointing) gestures. They are furthermore charged with a three-fold task they have to solve during the interaction. Namely, they have to ask for three different locations on the floor plan using different modalities in the following order: (1) auditorium (2) central inner courtyard (3) inner courtyard at the edge (cf. Fig. 7).

For retrieving (1), they should only use a verbal phrase, while users are requested to also incorporate pointing gestures towards the floor plan for both of the inner courtyards as to possibly generate obstructions during the interaction. One of the courtyards thereby is located at a much closer distance to the robot than the other, which lies at the outer limit of robot reach. For

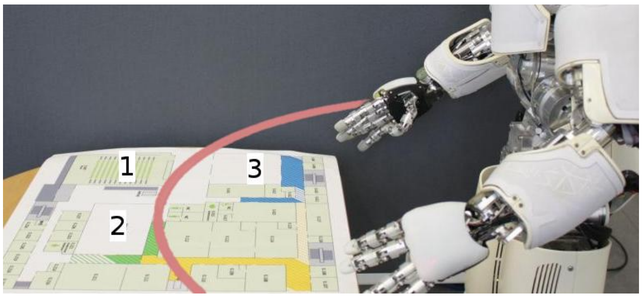

Fig. 7: Interactive area with a floor plan in front of the robot. A red line delimits the robot's reaching space. Numbers 1-3 denote the locations that should be asked for in the study.

enhanced reliability of speech recognition and a minimized participant distraction from their task, verbal input is not recorded via the wearable microphone but, with the help of utterance templates, typed in by the experimenter instead. After the interaction completes, participants are asked to return to the briefing computer to fill out a questionnaire about the interaction. After clarifying the instructions, the investigator enters the experiment room to hide behind the visual cover, prepare the scenario and type in verbal utterances of the participants. Shortly afterwards, a signal is given to the participant who then follows into the room, approaches the robot, and solves the imposed tasks.

3.5 Measurements

After the interaction, participants answer a questionnaire, available in both their native language (German) as well as English. In order to keep it short and simple, all questions are asked as single-item questions on a 5-point scale [36] except stated otherwise. The questionnaire starts with a self-assessment of robot and computer experience aimed to assure a simple entry paired with a motivation to fill it out. Participants then rate the robot behaviour in seven general questions about: (i) the robot's expressed interest in the participant (ii) the appropriateness and (iii) the human-likeness of its behaviours, (iv) how natural the robot moves, (v) how much attention it pays to the participant, (vi) how autonomous its actions are, (vii) and finally how much it reveals its attentions.

On the next page, questions regarding the opening follow. At first, participants choose the moment when they think they have been noticed by the robot for the first time from six options including an open-ended option. Then, we ask two questions regarding the opening of the interaction: (i) the robot's amount of willingness to interact during approaching, and (ii) how much the participants feel encouraged to interact with the robot. Participants further answer a *Yes/No* question whether they recognize any autonomous robot greeting.

Participants rate the robot behaviour at the dialogue phase on another page. Besides questions about the informative content of the different behavioural aspects (gesture, gaze, and floor plan), we ask two questions about how much either one's gestures interfere with the other. Participants chose between *Yes/No/I don't know* in two questions whether they think the robot or their own behaviour changes between the second and third task, i.e. the two courtyards where the participant has to use gestures. The questionnaire ends with questions about personal information (age, gender, native language, German/English knowledge, and occupation) as well as experiment feedback to estimate participant composition and attitude towards the experiment.

Moreover, the interactive system constantly records log files that contain information about the entire robot behaviour. Log files hold information like the type of robot's gestures and whether there have been any interferences. Also, all robot utterances and their causes are logged, which makes it possible to infer whether for example a greeting is initiated by the robot or human.

4 Results

This section illustrates the outcome of the interaction study with the interactive robot. After a general overview, results from analysing the questionnaire about the integrated opening are presented, followed by a description of outcomes for the dialogue phase (cf. Section 3.4). Finally, the interaction closing and departing are then characterized with the help of experimenter observations and system logs at the end of this section.

To determine significant deviations between answers in the different conditions, a Kruskal-Wallis test [33] is employed for ordinal data obtained from rating questions that have been answered on a (0-4) Likert scale [36]. A χ^2 test of independence [48] is utilized in case of nominal data (e.g. *Yes/No* questions). Furthermore, a χ^2 goodness of fit test against equal probability is used to distinguish preference from chance for each decision inside each condition.

Participants' answers that characterise the interaction in general, which are descriptive nature, are presented in the following. Ratings of the general robot behaviour (robot interest, appropriateness of behaviours, human-likeness, naturalness, robot autonomy, clarity of robot intentions, attentiveness) are all rated above their arithmetic mean value (cf. Fig. 8a). The robot's

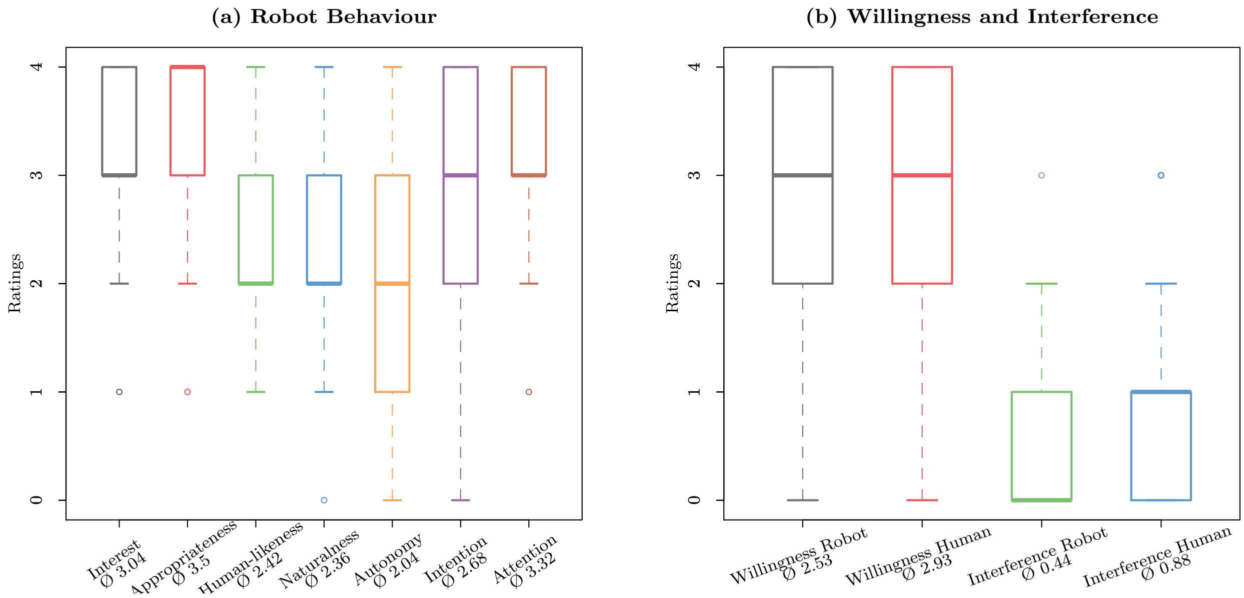

Fig. 8: Box-plots containing all 90 participants' opinion about the entire interaction with the robot. Part (a) displays general ratings of the robot's behaviour. (b) gives ratings about the robot's and the participants' own willingness to interact as well as the amount of perceived interference caused by both interaction partners.

interest in and its amount of attention towards the participant as well as the appropriateness of its behaviour are rated best with a value of greater than three. The robot's autonomy is rated lowest with a mean value of $\bar{x} \approx 2.04, \sigma \approx 1.00$. Furthermore, Figure 8b reveals that participants rate the overall perceived willingness of the robot to engage in the interaction very similar ($\bar{x} \approx 2.53, \sigma \approx 1.25$) to their own albeit marginally lower ($\bar{x} \approx 2.93, \sigma \approx 1.06$). General interference while carrying out gestures instead is rated below one on average, while participants rate their own presence as slightly more interfering ($\bar{x} \approx 0.88, \sigma \approx 1.05$) than the one of the robot on average ($\bar{x} \approx 0.44, \sigma \approx 0.69$).

Only statistically significant differences between experimental conditions are pointed out in the following. Excluded is a significant deviation in of age between the *Give-up* and *Prompting* groups with $\bar{x} \approx 27, \sigma \approx 6.24$ and $\bar{x} \approx 24.94, \sigma \approx 7.63$ years as it arguably does not imply any consequences. Also, a difference in robot and computer experience between the groups *Random* and *Full* is not further discussed. The average experience with computers is $\bar{x} \approx 1.56, \sigma \approx 1.1$ and $\bar{x} \approx 2.83, \sigma \approx 0.75$ with robots versus $\bar{x} \approx 0.9, \sigma \approx 1.02$ with computers and $\bar{x} \approx 2.35, \sigma \approx 0.98$ with robots. Such a difference may have an influence but the *Random* control group rates itself higher so a decrease of effect size is expected at most.

4.1 Initiation signal

The only significant difference between the *Weak* and *Strong* opening styles can be found in answers to the question of whether participants realise that the robot greets them or not. Participants who experience a strong initiation signal negate the question significantly more often as the other group (72% not noticing, $\chi^2 = 6.2354, p \approx 0.013$). Both groups, however, do not significantly differ from overall answers to the question (41% notice the robot-initiated greeting) but the effect between the tow groups is reliably distinguishable from chance ($\chi^2 = 9.383, p \approx 0.002$). This effect is supported by system behaviour logs that attest that a human-initiated greeting occurs in 93% of people in *Strong* as opposed to only 54% of people in *Weak*.

The videos recordings from the camera behind the robot also show that everyone immediately turns towards iCub and starts to approaching the desk. This finding is in contrast to trial runs where some participants showed behaviours of disorientation or searching for a robot to interact with.

4.2 Integrated interaction opening

This section describes differences that occur between the three opening conditions *Random*, *Full*, and *Delayed*. In none of the general questions regarding robot properties statistically relevant differences occur. Instead, differences in the rated willingness to interact as well as the perceived means of opening appear and are illustrated in the following.

At first, Figure 9 gives insights about participant ratings regarding their own willingness to take part in the interaction (Fig. 9a) as well the same perceived willingness of the robot (Fig. 9b). With an average of above three, participants rate their own as well as the robot's disposition highest in the *Full* dynamic condition. *Random* only movements during approaching, on the other hand, result in distinctly lower self-assessment of willingness compared to the dynamic condition. In the group experiencing dynamic attentive behaviour with a *Delayed* robot greeting, the willingness of both, robot and human is rated significantly lower as in the group receiving an immediate salutation upon entering the close social distance.

Regarding the perceived opening, the *Full* dynamic group also differs from the others as depicted in Figure 10. At first, in this group, participants significantly earlier realize that the robot identifies them as a possible interaction partner compared to the *Random* group. Groups *Delayed* and *Random*, on the other hand, are neither distinguishable from each other nor the overall results (cf. Fig. 10a). Furthermore, a robot initiated greeting is mostly noticed in the *Full* dynamic group as opposed to all other groups. Instead, in the *Delayed* as well as in the *Random*-only conditions, a salutation by the robot is not experienced in a significant majority of cases as illustrated in Figure 10b. This observation is supported by the interaction logs which show similar percentages. Everyone in group *Random* as well as 86% of people in *Delayed* in contrast to 28% in *Full* take the initiative and greet the receptionist robot themselves.

4.3 Face-to-face interaction

During the interaction with the robot at the table, in 56 trials, no interferences can be observed half of which no pointing gesture towards the floor plan is carried out and the other half no hindrances occur. In total, 34 cases of disturbances of the robot's gesture in the shared interaction space occur. Four times the first gesture has been blocked, four participants cause alternatives to be triggered in both gestures, and 25 of them interfere with the second pointing gesture. In 16 trials, the robot incorporates spatial prompting strategies, while in the other 18, the gesture is aborted immediately. In the prompting case, which often involves multiple attempts, five times it has been exhibited prior to a pointing gesture, while also five times, pointing had to be interrupted in order to allow for prompting. In two cases, the hand is switched for prompting and in two cases, the final pointing gesture is carried out with the left hand. Eight times, the gesture is aborted because the hindrance occurs at a close distance to the robot and one time, the gesture is aborted after prompting four times in a row.

Altogether, participants rate the helpfulness of information delivered by the interactive receptionist system with an average of 3.09 of 4. The robot gesture as well as the illustration of the floor plan both strongly contribute to the informative content of the explanation. A significantly lower impact compared to the other components as well as in contrast to the overall content is given with the robot's gaze, with an average of 2.43 (each $p < 0.001$).

There are significant variations between the groups not only for the perceived interference caused by actions of the robot but also for the ones participants carried out. In each condition involving robot gestures, these gestures have been perceived as more interfering ($\bar{x} \approx 0.178$) in comparison to the *None* condition ($\bar{x} \approx 0.535, K = 5.2612, p \approx 0.022$ without conflicts; $\bar{x} \approx 0.588, K = 6.3642, p \approx 0.012$ with conflicts). Participants rate their own gestures as also interfering ($\bar{x} \approx 0.679, K = 7.6303, p \approx 0.006$, without conflicts; $\bar{x} \approx 1.588, K = 22.966, p \approx 0.000$ with conflicts) if the robot uses gestures during the interaction. Additionally, there is a significantly higher perception of their own interference in cases when the robot gesture is interrupted as opposed to non-conflicting gestures ($K = 9.2936, p \approx 0.002$).

Figure 11 reveals that, in contrast to *Regular* pointing and the *Give-up* strategy, gestures involving spatial *Prompts* increase the perceived interference produced by the robot but are not significantly different from the *None* group where no gesture was exhibited. Participants, on the other hand, rate their own interference on robot gestures higher if the robot gestures are interrupted with no observable difference between robot *Prompting* and discontinuation (*Give-up*).

Besides the perceived interference, participants also actively notice a change in the robot's way to carry out the pointing gesture towards the floor plan. In the case of no hindrances and no gesture, participants largely consistently state that there is no change in the robot's behaviour. In case of blocked gestures instead, participant answers differ significantly from the others as they detect a change more often. While spatial prompting, as well as simple discontinuation, can both be distinguished from the group with no gesture ($\chi = 6.8508, p \approx 0.009$ with discontinuation, $\chi = 10.748, p \approx 0.001$ with prompting), the give-up strategy cannot reliably be separated from regular pointing in contrast to answers in the prompting group ($\chi = 4.5352, p \approx 0.033$).

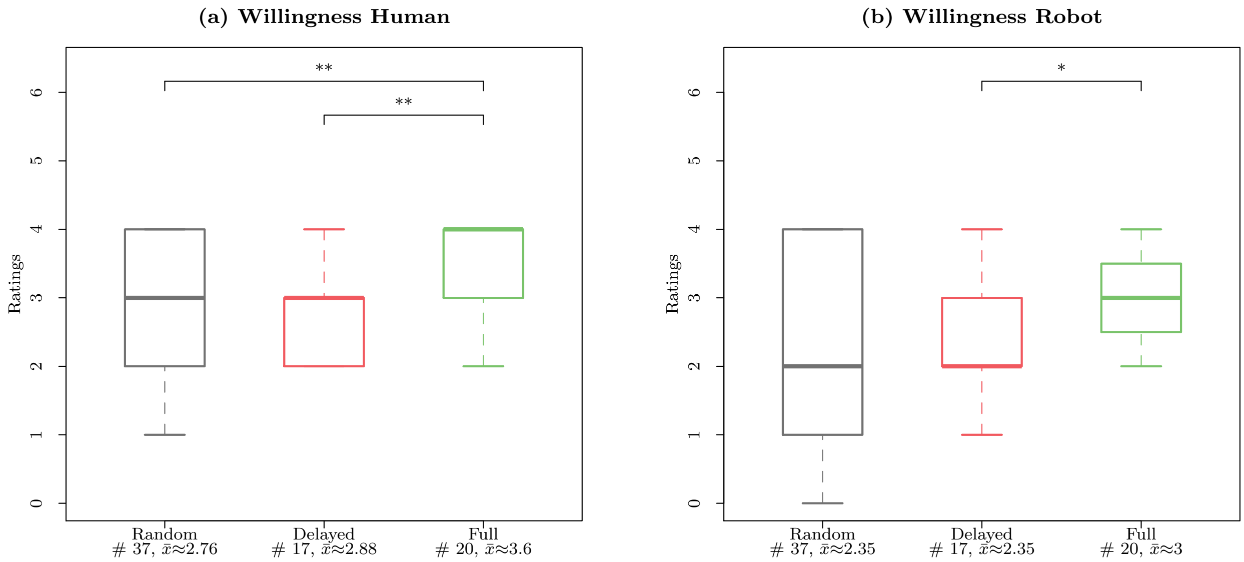

Fig. 9: Box-plots containing ratings of willingness to take part in the interaction grouped by opening strategy. In part (a) opinions regarding the own willingness is displayed while part (b) gives the ratings of the perceived robot willingness. Significance levels ($* := p < .05$, $** := p < .01$, $*** := p < 0.001$) resulting from the independence test between the experimental conditions are given as bars between the boxes.

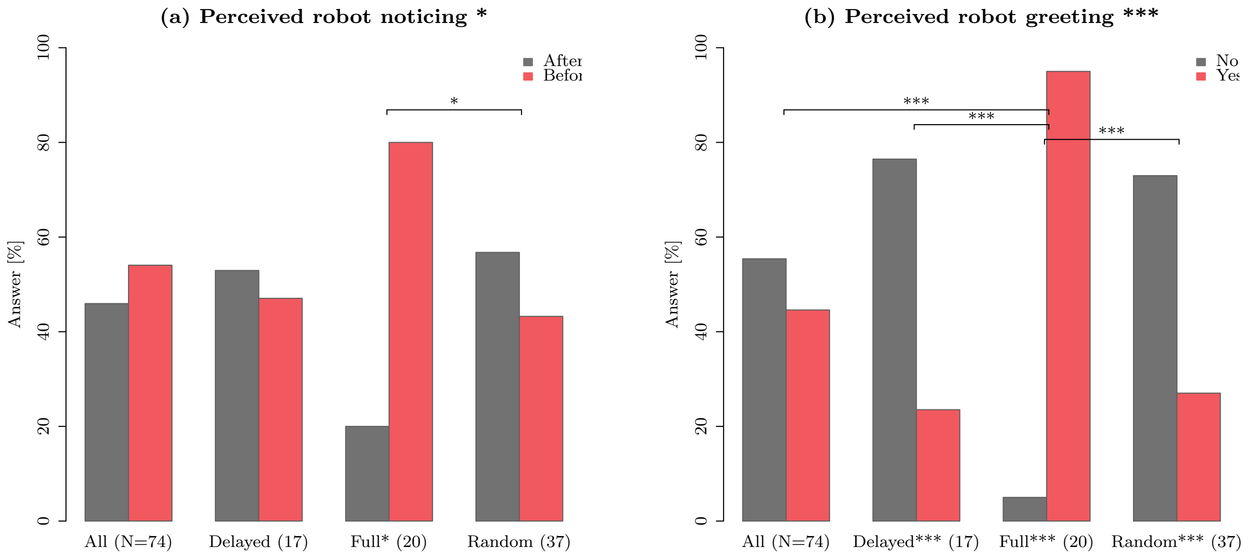

Fig. 10: Perceived robot awareness during approaching and dialogue opening grouped by emitted behaviour. In (a) it is displayed at which time during the encounter people think that the robot notices them. (b) reveals if participants notice a greeting initiated by the robot. Significance levels are given along the columns, as bars between the columns, and at the title.

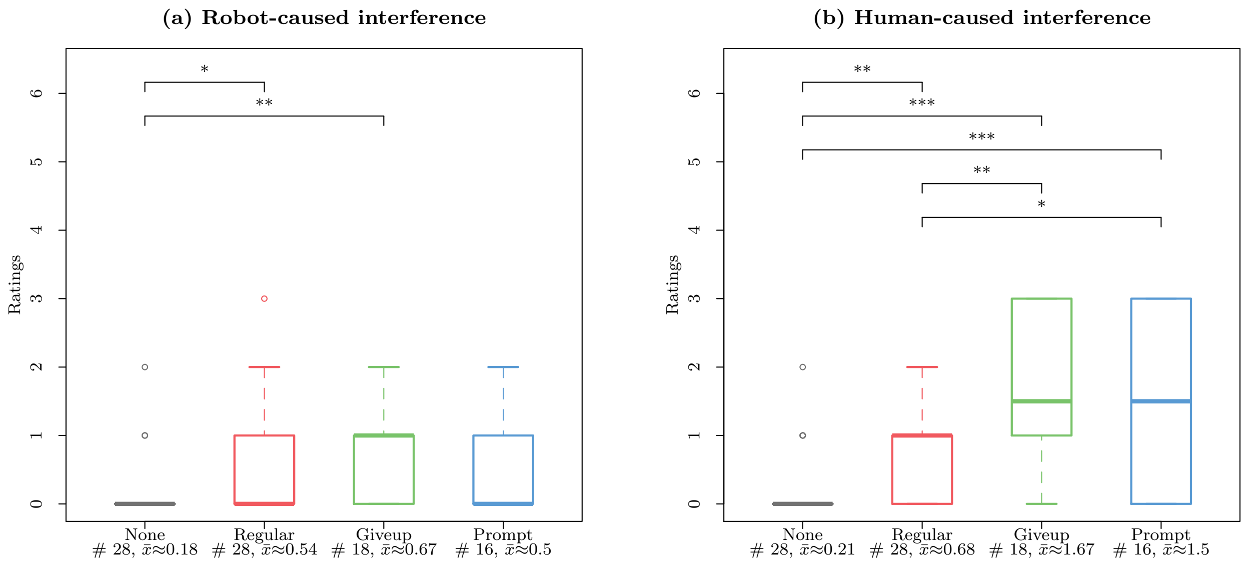

Fig. 11: Box-plots containing ratings of perceived interference during the interaction. In part (a) interferences caused by the robot are displayed and grouped by the experienced behaviour. Part (b) is grouped in the same way and gives ratings of perceived interference that participants cause themselves. Significance levels resulting from the independence test between the experimental conditions are given as bars between the boxes.

4.4 Ending the encounter

The questionnaire does not include questions explicitly directed at a closing signal or the departing phase. There are, however, observations of participant behaviour that have a direct impact on the way of proceeding during the study. Participants in the first 16 trials of the experiment wear a microphone for speech input that apparently induced several irritations. Furthermore, the robot does not exhibit an active interaction closing but stays engaged and waits for the participant to end the encounter. As a possible consequence, not a single participant returns to the experimenter after solving their assigned task although they are instructed to do so. Neither do they utter a farewell directed at the robot nor do they disengage it on their own. Instead, the majority of participants calls the experimenter and asks questions at the end of the interaction, whether the experiment is over. In cases where no such questions arise, people stay still in front of the robot until interrupted by the experimenter.

We have therefore removed the microphone and incorporated active robot closing strategies into the experiment in the following trials. After an active closing has been added to the repertoire of robot capabilities (cf. Section 2) only successful disengagement behaviours have been observed. Furthermore, the first 16 trials have been excluded from the evaluation of the robot's interaction opening strategies (cf. Section 4.2).

Table 2: Summary of experiment results by interaction phase

Phase	Observed effects
Initialisation	Human greeting & guidance
Opening	Human & percieved robot willingness
	Percieved robot awareness
Face-to-face	Human- & robot-caused interference
	Human awareness
Ending	Human departing & guidance

5 Discussion

The conducted study with the interactive receptionist robot has implications on the role of nonverbal signals in human-robot interactions and highlights the importance of a holistic view, cf. Table 2. According to the users' feedback, the robot's behaviours are rated excellently in terms of interest and attention. The amount of intention that the robot reveals as well as the overall appropriateness of its behaviours are also rated positive but to a slightly lesser extent. The system is also perceived as relatively human-like and natural.

The robot's autonomy rating, however, reaches only mediocre levels on average. On the one hand, the latter might be influenced by the inevitable circumstance of knowing an operator in the experiment room albeit hidden behind a covering wall. On the other hand, users might not expect such a comprehensive set of behaviours from an autonomous receptionist robot. Only six participants rate the robot as not autonomous at all, which suggests that most people are aware that the majority of the interaction is in fact autonomous.

Furthermore, it is noteworthy that ratings regarding robot properties do not differ significantly across all experimental conditions hinting at a self-explanatory and appropriate design of the interaction in addition to clear instructions during the study. Especially the way in which attention is expressed seems to work as intended. On the downside, possibly related to the overall high level of ratings or the relatively large number of intermixed experimental conditions, no clear distinction between behavioural categories can be drawn. Nevertheless, interesting differences emerge in questions especially addressing interaction instigation or conversation. In the following, these effects are interpreted in relation to Hypothesis 1 and related to claims established in Section 2.

5.1 Initialization

The experiment clearly shows that a short gaze as an initiation signal in still distant configurations works as intended and can lead to an immediate approaching behaviour of a human towards the robot. The strength of such a gaze, however, has to be adjusted to the specific purpose of the individual setup. A stronger signal in the form of a direct gaze towards the head and eyes might already cause human salutation utterances from a distance, whereas such an effect cannot be observed if the same gaze is exhibited in a less distinct fashion. If the robot is intended to demonstrate its potential during approaching including self-initiated greetings, it might therefore be inadvisable to use a very strong signal. In summary, Claim 1 can be approved based on the conducted experiment. An initiation gaze is recognized as an intentional communicative signal and thus allows the human to know that the robot is attentive and ready to be used.

5.2 Approaching

Furthermore, proximity and orientation-dependent attentional behaviours are well suited as a robot strategy during the approaching phase. Results from the conducted interactive experiment confirm the conclusions drawn from an earlier video study presented in [23]. No differences in general ratings of robot properties can be determined, which is perhaps caused by a large number of experimental conditions. Still, some opening-specific questions allow for inference on the selected behaviours. At first, participants are willing to take part in the interaction to a higher degree and also attest the robot the same. Secondly, participants are well aware that the robot notices them while they are approaching. As a result, Claim 2 can also be confirmed because said behaviours support the robot to lead a human into the interaction. The robot continuously confirms the participant's impression that it is socially approachable by expressing attention that matches the spatial configuration.

5.3 Opening

Answers to the questionnaire indicate a tight coupling between attentive approaching and pro-active robot greeting. The robot apparently builds up the impression of being sociable if it demonstrates increasing attention towards the human while they are coming closer. Participants consequently expect the robot to also open up the interaction. If the robot is not exhibiting attention, no difference in the robot's and participant's willingness to interact in comparison to random-only movements is identifiable. Above that, people only credit the robot the identification of themselves as an interaction partner during approaching if it does open up the interaction verbally. Possibly, participants interpret the attentive behaviours, which are also exhibited in the delayed one, falsely as non-interactive because of an expected greeting which does not occur. Claim 3, therefore, can be approved as it is not only appropriate to incorporate robot initiated opening but also required for a beneficial integration of attentive strategies prior to the dialogue.

5.4 Dialogue

Pointing gesture and utterance both are major contributors to the amount of information delivered by the receptionist which hints at a well-balanced interplay of gesture and speech. Gaze as a supportive cue instead has an expectedly smaller informative content but instead signals the robot's current focus of attention.

The amount of overall obstructions that occur in the interaction space justifies the incorporation of behaviours on the robot targeted at circumventing or solving them conveniently. The integration of spatial prompting thereby qualifies as an appropriate strategy. Apparently, it does not negatively affect the ratings of robot properties in the conducted user study. Other than a great majority of blocks occurring in farther distance from the robot, no further influence of distance can be determined. Nonetheless, the user experience regarding perceived interference is altered.

While movement alone results in some degree of interference, with prompting a relatively low amount of disturbances on the human, compared other robot movements seems to be caused. On the other hand, the participant is aware to cause collisions if the robot's gesture is aborted or if prompting is utilized, which confirms the effectiveness of prompting in terms of notifying of a desired pointing attempt and resolve ambiguities. Besides an altered impression of interference, participants also are aware of the gesture being carried out differently if spatial prompting happens in contrast to cases where the robot simply gives up. A plausible interpretation is that prompting reveals aspects of the robot's inner state without causing major disturbances to the interaction and therefore successfully addresses Claim 4.

5.5 Closing and departing

As an implication from observations, an appropriate closing strategy seems to be an essential part of the interaction. Nonetheless, Claim 5 can only be accepted preliminarily due to the lack of a dedicated experimental factorisation and questionnaire. We found, however, that an active strategy as outlined in Section 2.4 can effectively close a dialogue between a robot and a human. Such a strategy even seems to be expected to a similar degree as a proper greeting utterance because the human seems to not entirely know how to proceed if the robot does not employ it. If the robot actively closes the interaction using also proper non-verbal signals, disengagement behaviours of the human can be induced and accompanied. During the study, there has been no attempt of reengaging with the receptionist which makes it difficult to interpret the feasibility of decreasing attentiveness. However, the study also suggests the correctness of Claim 6 in the sense that nonverbal signals contribute to a seamless human receding. The interconnection between verbal dialogue opening and closing, as well as nonverbal signals furthermore supports the demand for an integrated and coordinated technique of emitting spatial signals with a social robot.

5.6 Limitations

With the presented study, which aims to provide a holistic view, exact interactions between the observed effects are difficult to prove due to the high number of overlapping experimental conditions. Moreover, no strict manipulation check has been conducted but individual behaviours have been inspired by previous studies [23, 24] to be part of a portfolio of behaviours for nonverbal signalling. As a result, the specific effects of the different behavioural cues of the robot are hard to discern. The experiment provides first evidence to support the hypothesis and the individual claims but the effects need to be confirmed and more specific the individual interactions need to be determined. We suggest a series of follow-up studies with distinct experimental conditions that each focus on an individual claim separately. At the same time, it would be interesting to further investigate the idea of a holistic concept and find effects of earlier phases on subsequent ones using validated sociability scales such as [8], which was not available at the time of the experiment.

We are aware that the use of a receptionist scenario implies certain roles that also set the humans expectations prior to the experiment. More specifically, the participants already know that one of the robots in the room is approachable and ready for an interaction. It would therefore be interesting to conduct a study where the role of the robot is less clear, for example in an open space like a library or museum.

6 Conclusion

In summary, interesting conclusions can be drawn from the interaction study with the social robot. While overall differences between the experimental conditions have been expected to be more distinct, especially in property ratings, a positive effect of the exhibited nonverbal behaviours can still be approved. Most importantly, the study reveals the following key findings i) A distance-dependent attention strategy can enable a robot to display its readiness and its willingness to interact much before an actual verbal conversation while ii) changes in spatial configurations between the robot and human can be used to effectively lead a visitor into and out of a conversation. Looking at an entire encounter, iii) effects of single behaviours on later phases of the interaction have been demonstrated. Finally, iv) during the dialogue itself, spatial prompting supports the robot in actively expressing territorial needs without disturbing the human excessively.

As a conclusion, Hypothesis 1 can be successfully approved. The incorporation of accompanying nonverbal behaviours into a social robot that strengthen the human's mental model leads to an enhancement in user experience. The study reveals that signals sent by the robot are in fact interpreted by participants as communicative acts that reveal information. As a consequence, the presented way of awareness assists the human in developing more appropriate expectations about the situation by the emission of attuned social signals in addition to its normal repertoire of actions.

In this work, a novel portfolio of social signals in human-robot interaction has been presented. For the first time, such a suite of behaviours covers an entire encounter between human and robot with appropriate signals that are attuned to each other. Its impact on user experience has been evaluated with a user study that installs an autonomous robot in an interactive scenario and applies behaviours for each phase of the interaction. The implemented strategies provide methods for an unconscious extension of the human's mental models leading to a better intuitive understanding of a social robot.

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Conflict of interest

The authors declare that they have no conflict of interest.

References

1. Andrist, S., Tan, X.Z., Gleicher, M., Mutlu, B.: Conversational gaze aversion for humanlike robots. In: 2014 9th ACM/IEEE International Conference on Human-Robot Interaction (HRI), pp. 25–32. IEEE (2014). DOI 10.1145/2559636.2559666 2.2, 2.2
2. Barnes, J., FakhrHosseini, M., Jeon, M., Park, C.H., Howard, A.: The influence of robot design on acceptance of social robots. In: 2017 14th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI), pp. 51–55. IEEE (2017). DOI 10.1109/URAI.2017.7992883 3
3. Bente, G., Krämer, N.C.: Psychologische Aspekte bei der Implementierung und Evaluation nonverbal agierender Interface-Agenten, pp. 275–285. Vieweg+Teubner Verlag, Wiesbaden (2001). DOI 10.1007/978-3-322-80108-1_29 1, 2.3
4. Bernotat, J., Schiffhauer, B., Eyssel, F., Holthaus, P., Leichsenring, C., Richter, V., Pohling, M., Carlmeyer, B., Engelmann, K.F., Lier, F., Schulz, S., Bröhl, R., Seibel, E., Hellwig, P., Cimiano, P., Kummert, F., Schlangen, D., Wagner, P., Hermann, T., Wachsmuth, S., Wrede, B., Wrede, S.: Welcome to the future – How naïve users intuitively address an intelligent robotics apartment. In: A. Agah, J.J. Cabibihan, A.M. Howard, M.A. Salichs, H. He (eds.) International Conference on Social Robotics (ICSR 2016), *Lecture Notes in Computer Science*, vol. 9979, pp. 982–992. Springer Berlin / Heidelberg, Kansas City, USA (2016). DOI 10.1007/978-3-319-47437-3_96 2.2
5. Boucher, J.D., Pattacini, U., Lelong, A., Bailly, G., Elisei, F., Fagel, S., Dominey, P., Ventre-Dominey, J.: I reach faster when i see you look: Gaze effects in human–human and human–robot face-to-face cooperation. Frontiers in Neurorobotics **6**, 3 (2012). DOI 10.3389/fnbot.2012.00003 2.1, 2.3
6. Braningan, H., Pearson, J.: Alignment in Human-Computer Interaction. In: K. Fischer (ed.) How People Talk to Computers, Robots, and Other Artificial Communication Partners, pp. 140–156 (2006) 2.1
7. Breazeal, C., Kidd, C.D., Thomaz, A.L., Hoffman, G., Berlin, M.: Effects of Nonverbal Communication on Efficiency and Robustness in Human-Robot Teamwork. In: International Conference on Intelligent Robots and Systems, pp. 708–713. IEEE (2005). DOI 10.1109/IROS.2005.1545011 1
8. Carpinella, C.M., Wyman, A.B., Perez, M.A., Stroessner, S.J.: The robotic social attributes scale (rosas): Development and validation. In: Proceedings of the 2017 ACM/IEEE International Conference on Human-Robot Interaction, HRI '17, p. 254–262. Association for Computing Machinery, New York, NY, USA (2017). DOI 10.1145/2909824.3020208 5.6
9. Castro-González, Á., Admoni, H., Scassellati, B.: Effects of form and motion on judgments of social robot's animacy, likability, trustworthiness and unpleasantness. International Journal of Human-Computer Studies **90**, 27–38 (2016). DOI 10.1016/j.ijhcs.2016.02.004 1
10. Crandall, J.W., Goodrich, M.A.: Characterizing efficiency of human robot interaction: A case study of shared-control teleoperation. In: International Conference on Intelligent Robots and Systems, pp. 1290–1295. IEEE/RSJ (2002). DOI 10.1109/IRDS.2002.1043932 1
11. Esposito, A., Jain, L.C.: Modeling Social Signals. In: Toward Robotic Socially Believable Behaving Systems-Volume II, vol. 106. Springer (2016). DOI 10.1007/978-3-319-31056-5 1
12. Fischer, K.: How People Talk with Robots: Reduce User Uncertainty. AI Magazine **32**(4), 31–38 (2011). DOI 10.1609/aimag.v32i4.2377 2.1
13. Gehle, R., Pitsch, K., Dankert, T., Wrede, S.: How to open an interaction between robot and museum visitor? strategies to establish a focused encounter in hri. In: Proceedings of the 2017 ACM/IEEE International Conference on Human-Robot Interaction, HRI '17, p. 187–195. Association for Computing Machinery, New York, NY, USA (2017). DOI 10.1145/2909824.3020219 2.2
14. Ghosh, M., Kuzuoka, H.: A Trial Attempt by a Museum Guide Robot to Engage and Disengage the Audience on Time. In: Winter International Conference on Engineering and Technology, pp. 18–22. Atlantic Press (2013). DOI 10.2991/wiet-13.2013.5 2.4
15. Gockley, R., Bruce, A., Forlizzi, J., Michalowski, M., Mundell, A., Rosenthal, S., Sellner, B., Simmons, R., Snipes, K., Schultz, A.C., Jue Wang: Designing robots for long-term social interaction. In: 2005 IEEE/RSJ International Conference on Intelligent Robots and Systems, pp. 1338–1343 (2005). DOI 10.1109/IROS.2005.1545303 2.1
16. Goodrich, M.A., Schultz, A.C.: Human-Robot Interaction: A Survey. Foundations and Trends in Human-Computer Interaction **1**(3), 203–275 (2007). DOI 10.1561/1100000005 1
17. Green, A., Hüttenrauch, H.: Making a Case for Spatial Prompting in Human-Robot Communication. In: Proceedings of the fifth international conference on language resources and evaluation (LREC2006) workshop: Multimodal corpora: from multimodal behaviour theories to usable models (2006) 2.3
18. Guitton, D., Volle, M.: Gaze control in humans: eye-head coordination during orienting movements to targets within and beyond the oculomotor range. Journal of neurophysiology **58**, 427–459 (1987). DOI 10.1152/jn.1987.58.3.427 3.1
19. Hall, E.T.: The Hidden Dimension. Doubleday, Garden City (1966) 2, 2.2

20. Hall, E.T., Birdwhistell, R.L., Bock, B., Bohannan, P., Richard Diebold, A., Durbin, M., Edmonson, M.S., Fischer, J.L., Hymes, D., Kimball, S.T., Barre, W.L., Lynch, F., McClellan, J.E., Marshall, D.S., Millner, G.B., Sarles, H.B., Trager, G.L., Vayda, A.P.: Proxemics. Current Anthropology **9**(2/3), 83 (1968). DOI 10.1086/200975 1, 3, 2.2, 5, 3.3, 6
21. Heenan, B., Greenberg, S., Aghel-Manesh, S., Sharlin, E.: Designing social greetings in human robot interaction. In: Proceedings of the 2014 Conference on Designing Interactive Systems, DIS '14, p. 855–864. Association for Computing Machinery, New York, NY, USA (2014). DOI 10.1145/2598510.2598513 2.2, 2.2, 2.2
22. Hegel, F., Gieselmann, S., Peters, A., Holthaus, P., Wrede, B.: Towards a Typology of Meaningful Signals and Cues in Social Robotics. In: International Symposium on Robot and Human Interactive Communication, pp. 72–78. IEEE, Atlanta, Georgia (2011). DOI 10.1109/ROMAN.2011.6005246 1, 2.1
23. Holthaus, P., Pitsch, K., Wachsmuth, S.: How Can I Help? - Spatial Attention Strategies for a Receptionist Robot. International Journal of Social Robotics **3**(4), 383–393 (2011). DOI 10.1007/s12369-011-0108-9 2.2, 2.2, 3.1, 5.2, 5.6
24. Holthaus, P., Wachsmuth, S.: Active Peripersonal Space for More Intuitive HRI. In: International Conference on Humanoid Robots, pp. 508–513. IEEE-RAS, Osaka, Japan (2012). DOI 10.1109/HUMANOIDS.2012.6651567 2.3, 5.6
25. Holthaus, P., Wachsmuth, S.: The Receptionist Robot. In: International Conference on Human-Robot Interaction, pp. 329–329. ACM/IEEE, Bielefeld, Germany (2014). DOI 10.1145/2559636.2559784 3
26. Jung, J., Kanda, T., Kim, M.S.: Guidelines for Contextual Motion Design of a Humanoid Robot. International Journal of Social Robotics **5**(2), 153–169 (2013). DOI 10.1007/s12369-012-0175-6 2.3
27. Kampe, K.K.W., Frith, C.D., Dolan, R.J., Frith, U.: Psychology: Reward value of attractiveness and gaze. Nature **413**(589) (2001). DOI 10.1038/35098149 2.2
28. Kendon, A.: Some functions of gaze-direction in social interaction. Acta Psychologica **26**, 22 – 63 (1967). DOI 10.1016/0001-6918(67)90005-4 1, 2.2
29. Kendon, A.: Conducting interaction: Patterns of social behavior in focused encounters. Cambridge University Press (1990) 2, 2.2, 2.2, 2.2, 3.3
30. Kendon, A.: Gesture. Annual Review of Anthropology **26**, pp. 109–128 (1997). DOI 10.1146/annurev.anthro.26.1.109 2.3
31. Knapp, M., Hall, J., Horgan, T.: Nonverbal communication in human interaction. Cengage Learning (2013) 1
32. Krämer, N.C.: Social Communicative Effects of a Virtual Program Guide. In: T. Panayiotopoulos, J. Gratch, R. Aylett, D. Ballin, P. Olivier, T. Rist (eds.) Intelligent Virtual Agents, *Lecture Notes in Computer Science*, vol. 3661, pp. 442–453. Springer Berlin Heidelberg (2005). DOI 10.1007/11550617_37 2.4
33. Kruskal, W.H., Wallis, W.A.: Use of Ranks in One-Criterion Variance Analysis. Journal of the American Statistical Association **47**(260), 583–621 (1952). DOI 10.1080/01621459.1952.10483441 4
34. Lee, M.K., Kiesler, S., Forlizzi, J.: Receptionist or Information Kiosk: How Do People Talk With a Robot? In: Computer Supported Cooperative Work, pp. 31–40. ACM (2010). DOI 10.1145/1718918.1718927 3
35. Leite, I., Martinho, C., Paiva, A.: Social Robots for Long-Term Interaction: A Survey. International Journal of Social Robotics **5**(2), 291–308 (2013). DOI 10.1007/s12369-013-0178-y 1
36. Likert, R.: A Technique for the Measurement of Attitudes. Archives of Psychology **140**, 1–55 (1932) 3.2, 3.5, 4
37. Lindner, F., Eschenbach, C.: Affordances and affordance space: A conceptual framework for application in social robotics. In: J. Seibt, R. Hakli, M. Norskov (eds.) Social Robots and the Future of Social Relations, *Frontiers in Artificial Intelligence and Applications*, vol. 273, pp. 35–45 (2014). DOI 10.3233/978-1-61499-480-0-35 2.1
38. Lohse, M.: The role of expectations and situations in human-robot interaction. In: K. Dautenhahn, J. Saunders (eds.) New Frontiers in Human-Robot Interaction, *Advances in Interaction Studies*, vol. 2, pp. 35–56. John Benjamins (2011). DOI 10.1075/ais.2.04loh 1, 2.1
39. Lütkebohle, I., Peltason, J., Schillingmann, L., Elbrechter, C., Wrede, B., Wachsmuth, S., Haschke, R.: The curious robot - structuring interactive robot learning. In: International Conference on Robotics and Automation, pp. 4156–4162. IEEE (2009). DOI 10.1109/ROBOT.2009.5152521 2.2
40. Makatchev, M., Simmons, R., Sakr, M., Ziadee, M.: Expressing Ethnicity through Behaviors of a Robot Character. In: International Conference on Human-Robot Interaction, pp. 357–364. ACM/IEEE (2013). DOI 10.1109/HRI.2013.6483610 3
41. Mehrabian, A., Ferris, S.R.: Inference of attitudes from nonverbal communication in two channels. Journal of consulting psychology **31**(3), 248 (1967). DOI 10.1037/h0024648 1, 2.1
42. Mejia, C., Kajikawa, Y.: Bibliometric analysis of social robotics research: Identifying research trends and knowledgebase. Applied Sciences **7**(12), 1316 (2017). DOI 10.3390/app7121316 1
43. Metta, G., Natale, L., Nori, F., Sandini, G., Vernon, D., Fadiga, L., Von Hofsten, C., Rosander, K., Lopes, M., Santos-Victor, J., Bernardino, A., Montesano, L.: The iCub humanoid robot: an open-systems platform for research in cognitive development. Neural Networks **23**(8-9), 1125–1134 (2010). DOI 10.1016/j.neunet.2010.08.010 3
44. Michalowski, M., Sabanovic, S., Simmons, R.: A spatial model of engagement for a social robot. In: International Workshop on Advanced Motion Control, pp. 762–767. IEEE (2006). DOI 10.1109/AMC.2006.1631755 3
45. Mondada, L.: Emergent focused interactions in public places: A systematic analysis of the multimodal achievement of a common interactional space. Journal of Pragmatics **41**(10), 1977–1997 (2009). DOI 10.1016/j.pragma.2008.09.019 2.2, 2.2
46. Pattacini, U.: Modular Cartesian Controllers for Humanoid Robots: Design and Implementation on the iCub. Ph.D. thesis, University of Genoa (2011) 3.1
47. Patterson, M.L.: A Sequential Functional Model of Nonverbal Exchange. Psychological Review **89**(3), 231–249 (1982). DOI 10.1037//0033-295X.89.3.231 1, 2.2
48. Pearson, K.: X. On the criterion that a given system of deviations from the probable in the case of a correlated system of variables is such that it can be reasonably supposed to have arisen from random sampling. Philosophical Magazine Series 5 **50**(302), 157–175 (1900). DOI 10.1080/14786440009463897 4
49. Peltason, J., Lütkebohle, I., Wrede, B., Hanheide, M.: Mixed-Initiative in Interactive Robotic Learning. In: Workshop on "Improving Human-Robot Communication with Mixed-Initiative and Context-Awareness" at International Symposium on Robot and Human Interactive Communication (2009) 2.4

50. Peters, A.: Small movements as communicational cues in HRI. In: "Pioneers" Workshop at International Conference on Human-Robot Interaction (2011) 2.3
51. Pinheiro, P.G., Ramos, J.J., Donizete, V.L., Picanço, P., De Oliveira, G.H.: Workplace emotion monitoring—an emotion-oriented system hidden behind a receptionist robot. In: Mechatronics and Robotics Engineering for Advanced and Intelligent Manufacturing, pp. 407–420. Springer (2017). DOI 10.1007/978-3-319-33581-0_32 3
52. Pitsch, K., Kuzuoka, H., Suzuki, Y., Sussenbach, L., Luff, P., Heath, C.: "the first five seconds": Contingent stepwise entry into an interaction as a means to secure sustained engagement in hri. pp. 985 – 991 (2009). DOI 10.1109/ROMAN.2009.5326167 2.2
53. Pitsch, K., Wrede, S., Seele, J.c., Süssenbach, L.: Attitude of german museum visitors towards an interactive art guide robot. In: International Conference on Human-Robot Interaction, pp. 227–228. ACM/IEEE (2011). DOI 10.1145/1957656.1957744 2.2
54. Rollet, N., Licoppe, C.: Why (pre)closing matters. the case of human-robot interaction. In: Mensch und Computer 2019 - Workshopband. Gesellschaft für Informatik e.V., Bonn (2019). DOI 10.18420/muc2019-ws-648 2.4
55. Salem, M., Eyssel, F., Rohlfing, K., Kopp, S., Joublin, F.: To Err is Human(-like): Effects of Robot Gesture on Perceived Anthropomorphism and Likability. International Journal of Social Robotics **5**(3), 313–323 (2013). DOI 10.1007/s12369-013-0196-9 2.3
56. Salem, M., Ziadee, M., Sakr, M.: Effects of Politeness and Interaction Context on Perception and Experience of HRI. In: G. Herrmann, M. Pearson, A. Lenz, P. Bremner, A. Spiers, U. Leonards (eds.) Social Robotics, *Lecture Notes in Computer Science*, vol. 8239, pp. 531–541. Springer International Publishing (2013). DOI 10.1007/978-3-319-02675-6_53 3
57. Satake, S., Kanda, T., Glas, D.F., Imai, M., Ishiguro, H., Hagita, N.: How to approach humans? strategies for social robots to initiate interaction. In: Proceedings of the 4th ACM/IEEE International Conference on Human Robot Interaction, HRI '09, p. 109–116. Association for Computing Machinery, New York, NY, USA (2009). DOI 10.1145/1514095.1514117 2.2, 3
58. Schegloff, E.A.: . In: J.E. Katz, M.A. Aakhus (eds.) Perpetual contact: Mobile communication, private talk, public performance, pp. 326–385. Cambridge University Press (2002) 2.2
59. Schulz, T., Soma, R., Holthaus, P.: Learning Lessons from Breakdowns - Participants' Opinions on a Breakdown Situation with a Robot. Paladyn, Journal of Behavioral Robotics: Special Issue Trust, Acceptance and Social Cues in Robot Interaction (2021 (in preparation)) 1
60. Sheridan, T.B.: Eight ultimate challenges of human-robot communication. In: International Workshop on Robot and Human Communication, pp. 9–14. IEEE (1997). DOI 10.1109/ROMAN.1997.646944 1
61. Shiwa, T., Kanda, T., Imai, M., Ishiguro, H., Hagita, N.: How quickly should communication robots respond? In: Proceedings of the 3rd ACM/IEEE International Conference on Human Robot Interaction, HRI '08, p. 153–160. Association for Computing Machinery, New York, NY, USA (2008). DOI 10.1145/1349822.1349843 2.4
62. Simmons, R., Makatchev, M., Kirby, R., Lee, M.K., Fanaswala, I., Browning, B., Forlizzi, J., Sakr, M.: Believable Robot Characters. AI Magazine **32**(4), 39–52 (2011). DOI 10.1609/aimag.v32i4.2383 2.1
63. Smith, J.M., Harper, D., et al.: Animal signals. Oxford University Press (2003) 1, 2.1
64. Stubbs, K., Wettergreen, D., Hinds, P.J.: Autonomy and Common Ground in Human-Robot Interaction: A Field Study. Intelligent Systems **22**(2), 42–50 (2007). DOI 10.1109/MIS.2007.21 1
65. Trovato, G., Ramos, J.G., Azevedo, H., Moroni, A., Magossi, S., Simmons, R., Ishii, H., Takanishi, A.: A receptionist robot for brazilian people: study on interaction involving illiterates. Paladyn, Journal of Behavioral Robotics **8**(1), 1–17 (2017). DOI 10.1515/pjbr-2017-0001 3
66. Wachsmuth, I., de Ruiter, J., Jaecks, P., Kopp, S. (eds.): Alignment in Communication: Towards a new theory of communication, *Advances in Interaction Studies*, vol. 6. John Benjamins Publishing (2013) 2.1