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Evaluation of Robot Body Movements Supporting Communication

Helge Hüttenrauch[1] and **Cristian Bogdan**[1] and **Anders Green**[1] and **Kerstin Severinson Eklundh**[1]
Dominik Ertl[2] and **Jürgen Falb**[2] and **Hermann Kaindl**[2] and **Michael Göller**[3]

Abstract. In designing socially interactive robots we have focused on robot movement and its role in multi-modal human-robot communication. In this paper we describe a user-centred design and evaluation process, investigating the idea of using speed and orientation adjustments as design elements in human-robot interaction. The scenario studied includes a robotic shopping trolley that offers products to the user while both are moving in a supermarket-like environment. Our results show that if the robot slows down while making such offers, users are more prone to react upon them. However, in an early pre-study, performed only with a robot mock-up, we observed that users tended not to notice the robot's slow-down movements while offers are made, even if these movements were shown several times to them during a video-based debriefing. This phenomenon, that users react implicitly on the robot's movements without being consciously aware of them, was confirmed during an experimental study with a fully integrated robot prototype. We discuss our results by reflecting on human-robot interaction design methods, and we propose implications from the lessons learnt in the study of the design of robot behaviours.

1 Introduction

Service robots that carry out tasks in homes, for instance hovering or lawn mowing, often use only uni-modal interfaces such as push buttons for input, showing the effects on small liquid-crystal displays. These types of robots are functionally designed for practical purposes [4] and therefore lack actuators, like arms, heads or a face, that could be used to provide additional multimodal output to enhance communication. When today's service robots move, these movements are primarily intended to bring about physical actions that support the service task of the robot. The research on spatially situated robots is yet in its infancy, and has focused on themes like approach directions, engagement space, comfort zones and appropriate distances between robot and user, etc. [19, 21, 23, 24, 27]. Our research is focused on how active engagement using the body in the communication between user and robot can be designed and evaluated [7,13]. The study presented in this paper challenges the current understanding of human-robot communication by extending the communication design to include full-body gesture intended to influence users as they are planning and performing an everyday activity: shopping in a supermarket. Our approach is to integrate the output of full-body gestures into the interaction design of a human-robot interface. Here the immediate goal is to increase the communicative capability of the specific type of robots we are investigating: Robotic Shopping Trolleys.

The rest of this paper is structured as follows; initially we introduce some concepts relevant for communication with full body gestures between humans and robots. Then we describe and report the findings from two user studies: an exploratory design study and an experiment. The exploratory design study was carried out using an enacted robot prototype and was used to prepare for an experimental study for which a real robot was used.

2 Background and related work

Arguably human body movements may have communicative effects, and thus be interpreted as gestures. When people are turning towards something, change their position or speed of walking during conversation, they convey meaning. In some cases this might be conventionalised, such as turning towards some object to carry out a deictic reference. Such body gestures are interleaved with ordinary movements – without symbolic meaning or lexicalised content, like walking or standing.

Mobile robots are also able to perform gestures using their bodies. It is therefore plausible to analyse them using the same type of concepts as used in human-human communication. This means that robotic gestures, like human body gestures, may function like utterances on their own, used in alternation or conjunct with linguistic information [15]. Another dimension of human movement is the ability to adapt to each other's movements, something which also has been shown to be relevant for human-robot interaction [27].

Central to the notion of situated interaction is the notion of shared space, the so called o-space, or the transactional space which can be described as an area, normally located in front of the interlocutors, where the interaction is conducted [1]. Full body gestures characterised as body moves can provide meta-discursive information in co-occurrence with information from other modalities or by themselves [5]. This pragmatic dimension aggregates commitments, or social obligations [22] by the participants that are bodily involved in the activity at hand.

Human body gestures fall within a type of gesture that are less conventional than for instance emblems that provide conventionalised ways of signing commands like "stop" or extending the index finger to display that the gesture conveys some type of deictic in-

[1] KTH School of Computer Science, Royal Institute of Technology, 100 44 Stockholm, Sweden, email: {hehu, cristi, green, kse}@csc.kth.se
[2] Vienna University of Technology, Institute of Computer Technology, Vienna, Austria, email: {ertl, falb, kaindl}@ict.tuwien.ac.at
[3] Research Center for Information Technology (FZI), Karlsruhe, Germany email: {goeller}@fzi.de

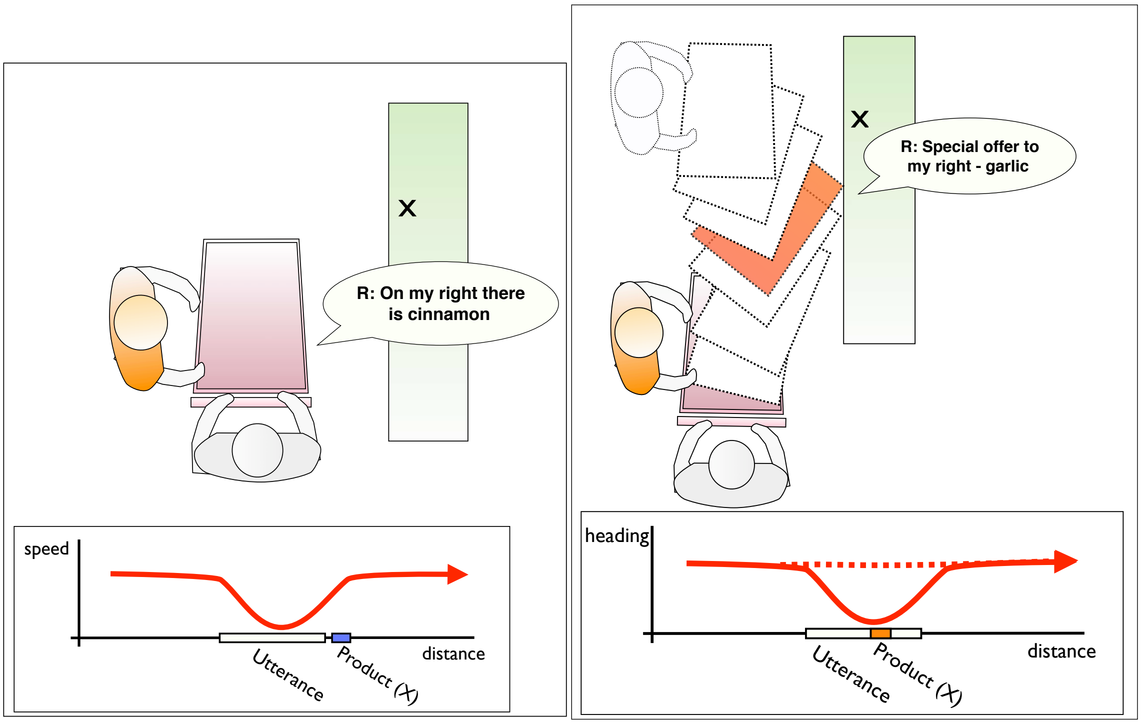

Figure 1. **I: Slowing down:** The figure shows how the robot slows down while providing the speech output (left).
II: Pointing: Trolley turns its body to point on the object while maintaining its trajectory (right).

formation. Instead, body movements convey additional information to an utterance given in some other modality, such as focusing on something by leaning into a work space [5].

2.1 Social spatial behaviour in Human-Robot Interaction

There are several research approaches for human-human interaction regarding social spatial behaviour that are relevant to study human-robot interaction, for instance Hall's work on interpersonal distances [10] has been used as a backdrop for studies on approach direction and comfort distances [23, 24]. Concepts drawn from theories on human communication such as work space [1] have been used to model situated interaction between humans and robots. One example of this is the tutoring system described by Sidner et al. [19], where the notion of a work space or engagement space is used as a fundamental configuration for the unfolding interaction between human and (robotic) tutor. The robot in this particular system was used as a pointing device, to guide the attention towards objects and to perform meta-conversational communicative actions, i.e, conversational feedback. Another approach that involves social models of spatiality is, for instance, the receptionist robot described by Michalowski et al [18], that estimated the degree of engagement based on spatial proximity. Tasaki et al. [21] describe a museum robot that uses a "Friendliness Space Map" to model the attitudes of visitors towards the exhibition. In their system, a humanoid robot in a fixed position, they varied the parameters for what type of communication the robot should engage in, based on a model of spatial proximity and positioning. Furthermore Hüttenrauch et al. [11] found that humans adjusted their spatial distance in relation to their imminent task.

In the approaches listed above body movements or bodily configurations are used by robots to spatially influence the interaction partner in an implicit manner rather than attempting to achieve some specific conventional communicative effect. The remainder of this paper will focus on robotic full body gestures that are carried out with the intent to evoke a communicative effect.

3 Methodological approach

As methodological approach we have chosen user-centred design adapted to human-robot interaction [8]. Preceding the work described in this paper we went out to study shopping using ethnographically inspired methods, observing shopping patterns and how shopping trolleys were used. We have also adapted video prototype techniques [17] to the human-robot interaction situation, as the interaction enactment which comes from creating video-prototypes captures the dynamic and embodiment aspects of interaction. This would otherwise only be attainable using more complex setups involving full-scale robot hardware using complex control mechanisms or hi-fi-simulation [2, 9]. Using video prototypes we were also able to invite users to reflect on their interaction with the robot [20]. In the final phase we have carried out a controlled experiment to evaluate our human-robot interaction design which is the main focus of this paper. In the following we describe two steps in this evaluation process:

- An initial, qualitative design study, focusing on user participation and reflection over some full body robot gestures.

- An experimental study of one specific robotic body gesture.

4 Initial exploratory design study

To explore the design space for robotic body gestures, we carried out an exploratory study. In the study we created a scenario and robot design involving robotic body movements that we enacted using an overt version of the Wizard-of-Oz simulation technique. Normally when performing a such a study, the operator is hidden and a real(istic) system is simulated without telling the user what is going on behind the scenes [9]. In our version the robot movements were controlled by a physically fully present robot navigator who operated a regular shopping trolley. We enacted the scenario in our laboratory, with props that would allow participants and experiment leaders to engage in a role-play that contain the conceptual components of shopping in a supermarket with a robotic trolley.

We invited 8 employees from the research institute where the study was carried out to participate in the study. The participants came from the same department, but they were not involved in the robot project. They all had experience of shopping, but not from any robotic shopping trolleys. Each participant was told about the general purpose of the study: to investigate the design of a supermarket trolley. Furthermore we informed them about the way the robot would be driven by a human operator, but said nothing about the robotic body gestures that they were going to experience. The instruction to the participants was that they would use a robotic shopping trolley to pick the ingredients needed to bake a cake.

The research questions we addressed in this design study were:

- Do robotic body gestures have a communicative effect?
- Do such gestures change the shopping behaviour of the users?

The robot design we wanted to evaluate involved two types of full body gestures:

- Slowing down: the robot slows down to allow the user to focus her attention to the immediate spatial context while uttering a phrase (i.e., “On my right there is cinnamon”, uttered right before the robot passed the product). (Fig. 1, I).
- Full body pointing: this gesture is a referential gesture that complements a verbal utterance, i.e., “Special offer to my right – sugar!” (Fig. 1, II).

To evaluate the appropriateness of these body movements we have analysed the scenarios in two ways. First we looked at what the users did when the robot displayed body gestures in the video recordings trying to see the effects of the gesture. This allowed us to judge to what extent the gestures influenced the interaction. We analysed where the participants looked, if they changed body direction and if they manipulated or mentioned any of the of products suggested by the robot. Taken together such behaviour of the participants was used to evaluate the communicative success of the robotic gestures. Secondly we interviewed participants after the interaction sessions. During the interviews the participants were shown video recordings showing parts of the interaction and were asked to reflect on it.

Some reflections concerned the shopping behaviour in general. Some participants assumed the robot to have some common sense knowledge about their overall shopping plan: “It [(garlic)] does not really fit my cake”, or, “Why did special offer concern garlic, it does not make sense for baking?”. The shopping list serves a manifest representation of the users’ shopping plans, rendering comments regarding the appropriateness of having the robot reminding them about items: “[It was] not on the [shopping] list”; “[I am] not usually buying things that are on offer”, and “If there was an offer every step it would have been annoying”.

When asked about the two gestures, users appeared to notice and comment on the referential (turning) gesture to a larger extent than the slowing-down gesture. However, even if they seem to notice the robot’s turning gesture, it is not identified as a referential gesture straightforwardly by the participants, indicated by reflections like: “Aha, and it didn’t go straight, it went a bit... to the right?” In general our interpretation was that the strength of the confidence they gave their own observations of the gesture were quite weak: “Well, on the movie it turned slightly towards the [product]. I don’t know if that was supposed to happen?”

More important, and the primary motivation for selecting the slowing-down gesture to evaluate in the larger experimental study, was that it seemed this gesture was not interpreted as a communicative act in itself. This supports our understanding that this gesture works as a complementary gesture. It seems that when the trolley slows down, users pay more attention to the spoken prompt, but that the slowing-down did not appear as a discernible gesture. In the reflection sessions some participants only noticed the slowing down when watching the sequence for the second (or even third time). The main contribution of the initial study was that it allowed us to formulate a hypothesis to test in the quantitative study, described in the following.

5 Experimental study

In the main study we present in this paper we have narrowed our focus of the research questions somewhat. Instead of two robotic gestures, we are now investigating only one, namely slowing-down. The research question is:

- Does the robotic body gesture *slowing down* (accompanied by spoken output) positively affect the amount of products taken by participants during a shopping round?

To test this we created a “supermarket aisle” in our laboratory. In a large room we placed a long shelf to form a 10 meter aisle (Figure 3). In the shelf we put about 10 different products that the robot had stored in its product database and could be scanned with the bar code scanner. The position of each product was also entered in the database. With this supermarket aisle we intended to give the user a sense of being in a real shop. Along the aisle the robot had its starting point and the stored location of the three products in the shopping list for which we had pre-programmed the robot to utter a spoken prompt and perform the slowing down gesture. The products were a soft drink (“Cola”), a bottle of bathroom cleaner (“Cleaner”) and a bottle of wine (“Wine”). At the end of the aisle we had placed the last product on the list: a bottle of shampoo (“Shampoo”).

The robot we used was the Interactive Behavior Operated Trolley (InBOT, see Figure 4). Its obstacle detection uses sensor information acquired from two 270 degree planar laser range finders. It uses an RFID transponder to detect barriers placed on the floor and stores these areas using topological relations. It uses odometry to keep track of its traveled distance when it navigates. The robot’s mecanum drive enables it to perform fully holonomic

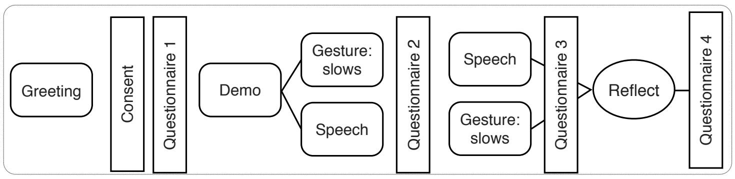

Figure 2. Study design

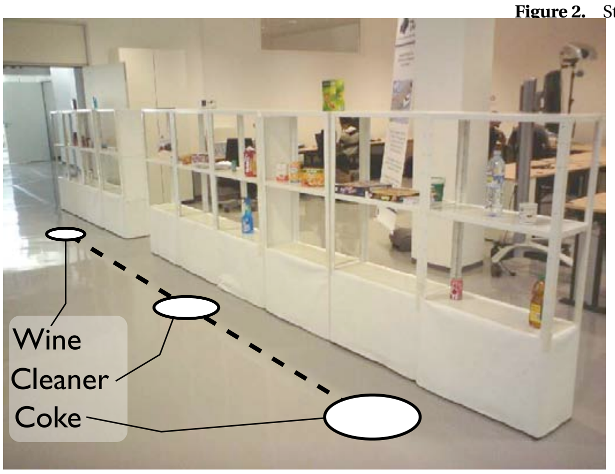

Figure 3. Shop corridor with shelf and products as it were built up in the laboratory used in the study.

movements. For more details on the architecture and control of the robot see [6].

We recruited 20 participants from the University of Karlsruhe campus, giving us a rather homogeneous group of participants both in gender (16 male, 4 female) and in age (average 24.1). Upon initial contact potential trial participants were invited to participate in a study to test "a prototype of a motorised shopping trolley", avoiding the word "robot" altogether. For their participation in the trial, participants received a small token of our appreciation in the value of about 5 Euro after participating.

Upon arrival the participants were greeted and informed about their task; shopping for multiple products using a prototype "motorised shopping trolley". They were also informed about their rights as participants and what type of data we recorded. After this they signed a consent form. After this the participants were asked to fill out a questionnaire about socio-demographic data and their shopping habits. Participants then were given a short introduction on how to operate the graphical user interface (GUI), see Figure 5. They were then given the opportunity to enter a shopping list into the system on the screen. They were then introduced to the full system including movements of the robot. The participants were asked to initiate and select a task on the graphical user interface which made the robot start and move to a product placed along the aisle.

The initial familiarisation with the trolley and its interface components was done by the participant but with the assistance of the experiment leader. Each participant was also explicitly asked to demonstrate their ability to use the components that they had been told about by the experiment leader. In this step they were informed about and got to try out the following functionalities of the robot:

Figure 4. The FZI-InBOT used in this study

- driving the trolley to a product,
- stopping the robot on its way by using the "Stop"-button on the touch-screen and/or the scanner, and finally,
- using the bar-code scanner to scan the product on the shopping list once the trolley had arrived at the product's position.

After this demonstration, the experiment procedure started. We gave the participants a print-out of a four item shopping list consisting of "Cola", "Cleaner", "Wine", and "Shampoo". The list was entered so that the robot had "Shampoo" as the first target location, meaning that the robot, when it passed all the other products on the list could, suggest them to the participant.

The setup of the study was identical for all participants up to this point. Then the robot used one of these strategies to influence the user during their shopping:

- During the mission the robot displays the full-body gesture "slowing down". The robot slows down while uttering "Here is ⟨product⟩ from your shopping list". This happens before the robot passes three of the products on the shopping list.
- The other run was with the same spoken utterances while passing the three products on the list, but without a full body gesture.

A schematic overview of the setup and study design can be seen in Figure 2.

After a participant had used the robot with one type of behaviour in the first run, we shifted behaviour so that the robot was used with the other behaviour in the second run.

After the first run participants were asked to fill out a questionnaire, asking about their impression of the shopping they just had performed. When they had answered the questionnaire, they used the robot with the other robot behaviour activated.

After completing the two different "shopping rounds", we asked the participants to run the robot again. In this run the full body, slowing down body gesture was displayed again (identical to the one in the trial round). This time the participants were asked to verbalise their experience using the think-aloud method [3]. When the robot carried out its slowing down gestures, the test leader asked them to reflect in detail of the robot's behaviour. After this reflective shopping round, the participants were asked to answer a questionnaire about the general idea of a "motorised shopping trolley". Finally they were debriefed and handed the small gift.

6 Results

The results of the study are based on the analysis of two data sources: the questionnaires and the video recordings of the different runs. The videos were annotated according to a predetermined metric from two annotators; for reasons of brevity only the most relevant aspects are presented here.

The statistical analysis based upon observations in video includes 15 participants that completed both test runs. For each participant we have measured the number of products the participant has taken. A participant could have taken between 0 and 3 products (Cola, Cleaner, and Wine). In Figure 6 the X-axis displays how many products the participants took. The frequencies of the products taken in the first run is shown in this figure. The right-hand side bar in each column shows the condition without gesture display and the left-hand side shows the condition with the full body gesture.

Participants using the robot that performed the full body gesture (slowing down) took more products than participants using the robot without it in the first run. The number of taken products correlates with the behaviour of the robot at 0.821 and is highly significant at the 0.01 level[4]. In the second test run, participants using the robot with the gesture behaviour took approximately the same number of products as participants using the robot without the gesture behaviour activated.

Figure 6. Frequencies of products taken in the first test run.

Based on the data of both runs we calculated a two-factorial ANOVA (analysis of variance) with the robot's behaviour and the run as independent fixed factors.

The ANOVA results in Table 1 show that participants take significantly (p=0.022) more products if the robot uses the full body gesture. Further, it shows that in a second run participants have learnt how to use the robot trolley and take significantly (p=0.003) more products than in the first run. When we look at both variables (run and body gesture enabled or not), we see that participants need to learn less between the runs if body gestures are enabled and that they initially take more products with body gestures enabled which drops to the same amount in further runs. Thus, there is a significant (p=0.001) interaction effect between these two variables.

Looking at the second run, we see a high learning effect that superimposes all other effects. Thus, we cannot say if an effect of the robot's behaviour is present starting with the second run.

While the measurement of products taken during the experimental runs are convincingly pointing towards the full body gesture of slowing down as having a clear and measurable effect, the *perception of this gesture* by users seems much more questionable.

One observation we made when analysing the experiments is that very few users reported that they had perceived some kind of gesture performed by the robot. Only 4 out of 20 participants clearly stated that they noticed the full body gesture of the slowing down trolley to indicate products. This is an remarkable outcome given that participants had the chance to experience two, to their nature, quite different trolley driving runs and thus handling experiences between the two runs performed right after one another. Most participants plainly stated that they had not spotted a difference between the runs, some commented on their *performance* or *learning experience*, or talked about other issues, e.g., the spoken utterance of the trolley, or the actual placement of the products.

Using the same approach as in the initial exploratory design study we let users watch the video of themselves interacting with

[4] The correlation value represents the Pearson correlation of a point-biserial correlation.

Figure 5. The Graphical User Interface used in the robot.

Table 1. Test of between-participants effects.

Dependent Variable:products

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	26,182[a]	3	8,727	11,059	,000
Intercept	112,634	1	112,634	142,728	,000
behavior	4,715	1	4,715	5,975	,022
run	8,715	1	8,715	11,043	,003
behavior * run	11,834	1	11,834	14,996	,001
Error	20,518	26	,789		
Total	155,000	30			
Corrected Total	46,700	29			

a. R Squared = ,561 (Adjusted R Squared = ,510) the robot in order to reflect on the user experience, and especially the full-body gesture of slowing-down.

The result of the video-taped and analysed reflective runs is interesting: Users were (again) led to the three products with the robot performing the slowing down gesture. But after every product the experiment leader and the participant took some time to go through a couple of standardised questions and discussed them together: "What did the trolley just do?", "What did the speech interface utter?", and "What did you do?", were questions to let participants express in their own words their experience they just had with the trolley.

Filtered for the full body gesture of slowing down this method could during this third run show more users being (or becoming) aware of this gesture as compared to the questionnaire data collected, however, from the 20 reflective runs performed, only 7 participants clearly expressed that they noticed the slowing down. Another 8 participants never realised even during the reflective runs that the robot trolley is slowing down. The remaining 5 cases are difficult to rate clearly, as participants for example hinted in their used expressions that they took advantage of the slowing down of the trolley, but never expressed this in clear terms in using words such as "braking", "slowing down", "reducing speed", or similar expressions to describe the robot's behaviour.

7 Discussion

7.1 Motivation for robotic body gestures

Throughout our work of designing movements as full body gestures that would properly accompany other robot communication, we have reflected on the details of how designed movement patterns can make robots more socially interactive.

When a human makes a deictic reference, a spatial relation needs to be established in order for the conversation partner to understand the reference made. We assume that the human behaviour corresponding to what the robot does in the slowing down phase of the study involves a deictic component of interaction that is both temporal and indicative. If a human would not accompany an utterance containing a deictic reference, with adjustments of their movement, i.e., keep the same walking speed and body orientation while referencing something in the surroundings, they may be perceived as non-collaborative (or even rude).

Some of our observations in the study can be better understood using this assumption as a backdrop. Some users in the condition without slowing down body gesture qualified the robot behaviour with negative characterisations such as "unfair", "I felt like a dog on a leash", or "I had to pay attention – stressful!".

Users who first received the condition without the slowing down gesture were more "on their watch" in their second run and stopped the robot more than the users who got the presumably more usable slowing down condition first. This suggests that users adapt to overcome flaws in the design.

Perception and execution of gesture in human-human conversation is sometimes carried out in what can be understood as the periphery of awareness, i.e., human language users do not (need to) pay attention to their specific body postures and gestures during communication. We perceive and adapt to body posture and gesture with little effort. In conversation we expect this adaptation to be performed by our conversation partners. It is part of the fabric of our social expectations and we rarely pay attention to them. We do however notice when they are missing.

This can explain what we regard as an interesting finding, which came out both of our exploratory design study and out of our experiment: few of our users noticed the robot's movement adaptation, even if it was shown to them on video in the pilot study with the mock-up robot. This was also the case in the experimental study, where very few users noticed the robot's full body gesture during the reconstruction runs.

This phenomenon may be related to information that is in the periphery, i.e, information which is being absorbed and understood without being in focus of attention [25]. Designing movement is then akin to designing calm technology [26], like ambient information displays [12] or other approaches for providing information without distracting the user. Our understanding of robotic body gestures is in accordance with [5], who regards meta-discursive actions crucial for spatially situated interactions. Robotic body gestures should therefore be considered carefully when designing human-robot communication.

7.2 Beyond making the first move

We are currently redesigning the movements and robotic body gestures of our robot and we are considering the issue of movement adaptations, and how they can be performed in a more structured way. This goes beyond the movement(s) accompanying a first, initiating utterance, taking into account the response. The theoretical framework we are using is based on the notion of adjacency pairs [16]. In such a model, each communicative initiative has a preferred response and deviation from this response leads to a state of miscommunication.

Applied to our context we understand the slowing down of the robot as an initiating move for which the preferred response is to slow down and show interest in the indicated product. If the user walks past a robot that slows down to show something, or even attempts to push the robot to move on, can be interpreted as active lack of interest in the product communication and negative response to the communicative action.

In our view such bodily ways of responding to communicative actions need to be taken into account when designing communication for robots. This means that body movements that indicate refusal of offers should lead to adaptation of the robot behaviour, possibly by decreasing the number of offers. Conversely acceptance of the robot offer could lead to an increase in offers made by the platform.

As a consequence of understanding robotic body gestures as the first part of an adjacency pair, we see the need to interpret and detect responses from human users. This requires machine perception that goes beyond the technical scope of this paper.

8 Conclusion

The fine spatial interplay between humans and robots is something that we are only beginning to understand. In this study we have focused our interest in one type of robot gesture, namely slowing down when passing a product. This can be contrasted with another approach taken by Kanda et al. [14] who used a conversational approach to achieve what they call an "Advertisement effect" triggered by verbal recommendations by the robot. This meant that the participants reported that they had been influenced in their shopping behaviour (for instance, buying ice cream because the robot suggested it). It should be noted that the anthropomorphic design of the robot used by Kanda et al. [14] allowed for a larger repertoire of gestures than the robot system we describe in this paper, involving eye gaze, pointing gestures using an arm manipulator. The automated robot trolley lacks such capacity, but our results show that accompanying spoken utterances with robotic body gestures lead to changes in the shopping behaviour of humans, i.e., there is an increase in the number of products taken during a shopping round. It appears that it is not necessary to employ a full-blown humanoid robot to influence the shopping behaviour of people.

We have yet to establish an explanation to why the full body gesture has an effect on the shopping behaviour. The explanation we suggest is that the slowing down gesture allows for the participants to better perceive the messages spoken by the robot while simultaneously looking around in the environment to find a suitable referent in the context of the robot. This line of reasoning is supported by the circumstance that when the robot passes a product and issues a spoken utterance (using the on-board speech synthesiser) *without slowing down*, it seems to lead to users being frustrated and reporting that they experience a sense of loss of control.

All in all this calls for a careful design of robot movements to accompany its communicative utterances, especially when they refer to objects in the environment. However, as our experience shows, due to the fact that it was hard for participants to notice the movements, designing and evaluating such movements pose interesting challenges. In our view this requires adaptation of user-centred design and evaluation methodology, as gestures that are close to what is being noticed by users affect the reaction, interpretation and communicative behaviour during design and evaluation sessions.

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