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The Influence of Approach Speed and Functional Noise on Users' Perception of a Robot

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Abstract— **How a robot approaches a person greatly determines the interaction that follows. This is particularly relevant when the person has never interacted with the robot before. In human communication, we exchange a multitude of multimodal signals to communicate our intent while we approach others. However, most robots do not have the capabilities to produce such signals and easily communicate their intent. In this paper we propose to communicate intent when a robot approaches a person through functional noise and approach speed. Both were manipulated in a between-subjects experiment (N=40) either slowly increasing at the start of the approach and slowly decreasing when the robot reached the human or maximized at the start and abruptly stopped at the end of the approach. We analyzed questionnaires and video data from the interaction and found that particularly functional noise that in-/decreased in volume was helpful to communicate the robot's intent *but* only in congruence with an in-/decreasing velocity.**

I. INTRODUCTION

The first impression of others, that has been found to crucially influence the communication between people [2], is already formed at the time of approach and before actual verbal communication starts. We assume that this holds true for human-robot interaction (HRI) and related work has actually supported this assumption (see Section II). Approaching means to come close enough to each other to start an interaction [7]. Whether an approach is successful and the first impression is positive or not depends on the social intelligence of the interaction partners [1] - in the case of HRI, the social intelligence of the robot. Thus, social skills are crucial for a successful initiation of any interaction. They are displayed in anyone's behavior and it has been shown that users also interpret robot behavior in a social way [8]. However, robots' capabilities to express themselves in subtle, e.g. non-verbal, ways like humans are very limited. Therefore, an important part of the behavior design for robots is to convey their intentions [14], to make them readable [19], predictable ([6], [9]), legible [12], and comply with users' expectations [13] in order to make users feel safe and positive toward the systems.

In this paper we design and evaluate robot behavior that communicates the system's intention while approaching people. Particularly, we investigate two factors and the interplay between them: the functional noise of a robot (constant noise vs. increasing/decreasing noise) and the gradient of approach velocity (constant velocity vs. increasing/decreasing velocity). These factors are highly relevant in everyday environments such as museums, offices, or hospitals where robots approach people that might not be prepared for the interaction.

II. RELATED WORK

Several contributions in the literature focused on *approach behavior* in HRI. Dautenhahn et al. investigated from which direction a robot could best approach a seated human [5] and measured human comfort during the approach. Walters et al. took this research one step further by comparing approaches towards people that were seated or standing in an open space or with their backs against a wall. They discovered that these situational factors influenced the comfort people felt when the robot approached from different directions [21]. Further research on approach directions has been conducted by Satake [18] in order to enable a robot to better approach people while they were walking.

In our own work we have explored the consequences of a robot approaching too close to the users and, thus, invading their personal space [17]. Our findings indicated that participants actually showed more compensatory behaviors toward a robot than toward a human. This finding is closely related to the issue of communicating intent with robots that is in the focus here. Users may not be able to interpret the robot's intent and know what to expect of the robot [13]. Thus, our goal is to design behavior in a way that supports the users' interpretation of the approaching robot based on the gradient of approach velocity and functional noise.

Different strategies can be used for a robot's approach velocity. A faster velocity implies that a robot will spend less time travelling, effectively increasing its economic output. However, a faster velocity has significant downsides as well. Nanoka et al. report a correlation between a robot's velocity and the level of surprise and fear experienced by participants [15]. Also Butler et al. identified a slower approach speed (0.5 m/s) as being more comfortable for participants than a faster approach speed (1.0 m/s) [4]. Previous research has mainly focused on these two categories: fast and slow velocity. We want to go beyond these studies by varying the gradient of velocity during the approach over time, thus, adding some visual information about the robot's intention to its behavior.

Furthermore, we want to research functional noise of the robot during the approach. The functional noise of machinery is often used as a warning sign. Research from the U.S. Department of Transportation showed that pedestrians

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and bicyclist were victims of a technological shift in the car industry, because hybrid vehicles often lack sufficient functional noise [16]. Therefore, new regulations obligate a minimum level of functional noise for hybrid vehicles. This kind of noise is one example of intentional sounds that are added to a product as opposed to consequential sounds that are generated automatically while using a product [20]. The intentional sounds are basically added to provide additional auditive feedback to the user [11]. We argue that they can also be exploited to communicate the intentions of robots.

While these two factors are interesting to us independent of each other, we are also interested in their interplay. Previous research has shown that if interactive agents behaved incongruently across modalities, participants liked them less and were less influenced by them [10]. Thus, we believe that congruity between a robot's multimodal behaviors leads to a more positive attitude of the users toward them.

III. HYPOTHESES

Related work has shown that people use visual cues (approach angle, speed, stopping distance) to interpret robots' intent. As has been mentioned before, also sound provides us with an indication of what actions a machine is about to perform [16]. Thus, we expect that the users will be most easily able to understand a robot if its behavior communicates intentions [14]. Furthermore, we expect that the users develop a more positive attitude toward the robot that they understand better. This leads us to our first hypothesis:

H1: People have a more positive attitude toward a robot that displays intentional audio/visual behavior compared with a robot that displays intention-neutral audio/visual behavior.

Thus, we expect that a more meaningful functional noise that in-/decreases in volume (as an indication of in-/decreasing speed) will be rated as being more helpful and that an in-/decreasing velocity will allow the robot to approach the participants closer.

Furthermore, we expect that the robot's behavior will be easiest to be interpreted when it is intentional and at the same time congruent across modalities (audio and visual) [10]. Again assuming that understandability of a system results in a more positive attitude, this results in our second hypothesis:

H2: People have a more positive attitude toward a robot that displays congruent audio/visual behavior compared with a robot that displays incongruent audio/visual behavior.

Thus, we assume that participants in the intentional and congruent condition with an increasing and decreasing velocity and functional noise will have a more positive attitude toward the robot than participants in the conditions with intention-neutral (constant) speed and sound or incongruent functional noise patterns and gradients of velocity. We expect this to show in the users' subjective perception of human-likeness, animacy, perceived intelligence, likeability, and perceived safety of the robot. We also hypothesize to find a more positive attitude in the analysis of the user's behavior with people having a more positive attitude smiling more at the robot and supervising it less closely with gaze.

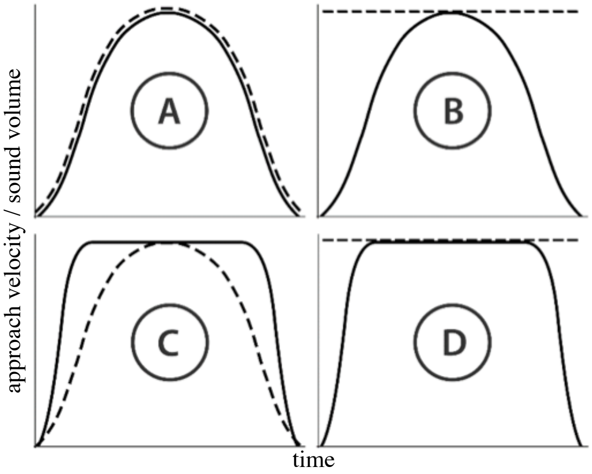

Fig. 1. Experimental conditions: dashed lines refer to functional noise, full lines to the velocity of approach. The x-axis represents time, the y-axis represents approach speed and volume of the functional noise.

IV. EXPERIMENTAL DESIGN

The hypotheses resulted in the design of a Wizard of Oz experiment with a 2x2 between-subjects design (see Fig. 1).

A. Experimental conditions

This research focuses on the gradient of approach velocity and the level of functional noise of a robot.

1) Gradient of velocity: We designed two distinct gradients of velocity. These are depicted in Fig. 1 (full lines). The x-axis represents time while the y-axis represents the velocity of the robot. In the two conditions at the bottom (C and D), the robot accelerates very quickly, comes toward the participant at high speed, and suddenly decelerates and comes to a final stop. The conditions on the top (A and B) depict a much more fluent way of both acceleration and deceleration.

The time to approach the users differed between the conditions because the robot always covered the same distance. In conditions C and D it took only 7.2 seconds for the robot to start the approach and stop in front of the human. The velocity of the robot was more or less constant in these conditions at 0.68 meters per second. In comparison, it took the robot 15.35 seconds to approach in conditions A and B. The velocity of the robot varied gradually. The maximum speed achieved was also 0.68 meters per second. However, this speed was sustained for only a very short period of time before the robot gradually slowed down again.

2) Functional noise: We created two different functional noises that were in line with the gradients of velocity (dashed lines in Fig. 1). In the first condition, the sound level of the robot was constant at a high volume (conditions B and D). In the second condition, the volume changed gradually increasing at the beginning and decreasing at the end (conditions A and C). It is important to keep in mind that the actual motor of the robot also made a certain level of noise. The fake functional noise, however, was louder than the noise of the motor.

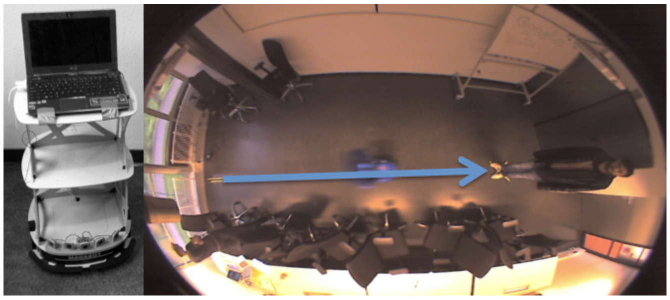

Fig. 2. Left: Magabot robot; Right: top view of the approach of the robot

B. Robot System

In this work we used a Magabot robot (http://magabot.cc/blog/; Fig. 2). The robot's overall height is 78 cm including the base, a plastic structure, and a laptop on top of it. It comes with an Arduino UNO board that is responsible for control of the wheels and sensors [11]. We were able to execute the behaviors for the conditions consistently by sending pre-defined strings over the serial port. The sounds that we used were edited from a car acceleration sound uploaded under a creative commons license online (Freesound.org: Car acceleration.mp3).

C. Procedure

We recruited most participants in the hall in front of the laboratory where we conducted the experiment. After signing a consent form, they were asked to stand close to a spot marked on the floor and to await the approach of the robot (see Fig. 2). The robot was located on the other side of the room and approached the participants according to one of the four experimental conditions that were chosen randomly. The approach distance was 4.9 m and the stopping distance was roughly 25 cm from the participants. The robot's approach was video recorded with one camera capturing both the robot and the user. The experimenter stayed in the room during the approach due to safety reasons. He tried to stay out of the line of sight of the participants in order to not attract any attention. After the robot's approach, the participants were asked to fill out a questionnaire (see Section IV-E).

D. Sample

40 people (20 males and 20 females) participated in this experiment. Their age ranged from 18 to 43 years with an average of 20.95 years (standard deviation (sd)=4.19). The majority of the participants were students from the University of Twente. None of them knew about the robot and the purpose of the experiment beforehand. The participants were divided over the four experimental conditions resulting in ten participants per condition (five male, five female).

E. Data Analysis

The analysis was based on self-report data of the users captured in a questionnaire and on behavior analysis that we conducted based on video recordings of the interaction.

1) Questionnaire: Our goal when using the questionnaire was to evaluate the participants' subjective impression of the robot. The first two items were designed to capture the manipulations in the conditions of our experiment:

- The robot approach speed was (1:too slow - 5:too fast)
- The robot sound was (1:too quiet - 5:too loud)

Another two items addressed mainly H1:

- The final distance between me and the robot was (1:too little - 5:too much)
- How helpful was the robot sound in anticipating its actions (1:not helpful - 5:very helpful)

The remainder of the questionnaire was used to evaluate mainly H2. It was based on the Godspeed scales by Bartneck et al. [3] that are 5-point Likert scale. We included all subscales (anthropomorphism (α=0.764), animacy (α=0.691), likeability (α=0.822), perceived intelligence (α=0.698), and perceived safety (α=0.303)). In our experiment, all scales but perceived safety turned out to be sufficiently reliable. After removing the item quiescent - surprised, the reliability of this scale also increased to an acceptable α=0.849.

Finally, the participants were asked for demographic information. The questionnaire was administered in English because many participants were no Dutch native speakers and students' proficiency in English can be assumed to be very high because they are also taught in English.

2) Behavior analysis based on video recordings: Next to what people reported in the questionnaire, we coded the video data of the robot's approach in order to analyze whether the participants' behavior differed between the conditions. We based the analysis on the five seconds before the robot stopped in front of the participants. We chose this interval for two reasons: Firstly, we decided to choose an interval because the experiment in conditions A and B where the robot accelerated and decelerated slowly took much longer than in the other conditions but we wanted to compare an equal amount of time for all participants. Secondly, we decided for the five second interval because this was the time when the robot started to decelerate in conditions A and B and the sound level started to decrease in conditions A and C. Therefore, if differences in the user's behaviors occur, they should be most obvious in this part of the interaction.

Within the interval, we coded the gaze direction of the users (towards robot, somewhere else), the number of gaze shifts (the number of gaze shifts that occurred after the beginning of the interval), and the facial expressions. The coding scheme for the facial expressions was simplified to two categories, namely smile and neutral, because hardly any other expressions occurred. The very few instances of a thoughtful facial expression were subsumed in the neutral category. No facial expressions with a negative valence were identified during data analysis.

37 out of the 40 participants were included in the video analysis because three participants did not agree to being video-recorded during the experiment.

V. RESULTS

In this section we introduce the results of the questionnaire and of the behavior analysis.

A. Manipulation checks

We first present the results of the questions that we asked to determine whether our manipulations, namely approach speed and loudness of functional noise, had actually worked. We only asked participants about their overall impression and not about in-/decreases because we wanted to avoid priming them with respect to the goal of the experiment.

1) Approach speed: Comparisons between the individual conditions with independent-samples T-tests showed that only the difference between conditions A (mean(m)=2.90, sd=0.568) and C (m=3.40, sd=0.516) were approaching significance (T(18)=2.060; p=.054). Thus, we observed a trend that participants in condition C felt that the robot was approaching them faster than users in condition A. Interestingly, these are the conditions with the similar functional noise (increasing and decreasing in volume). We hypothesize that the speed in condition C was particularly noticeable to the participants because of the inconsistency between constant speed and in-/decreasing volume of the functional noise. This would also explain why no difference was found to condition D in which the robot was effectively as fast as in condition C. The finding underlines the effect of the functional noise on the perception of the robot.

2) Volume of functional noise: An independent-samples T-test performed on conditions A (m=3.00, sd=0.471) and D (m=3.60, sd=0.843) indicated a trend that the participants in condition D perceived the robot to be louder (T(18)=1.964; p=.065). We take this as a sign that our manipulation has worked (A being quietest and D being loudest). However, there are no significant differences between conditions A and B and conditions C and D, respectively. One possible explanation for the lack of a clear pattern between the conditions and their respective level of functional noise is the actual noise produced by the robot's motor while driving.

B. Participants' comfort with the robot's stopping distance

Overall, the mean rating of the robot's stopping distance was 2.95 (on a scale of 1 to 5, sd=0.815). A one-way ANOVA revealed that the differences between the groups approached statistical significance (F(3,36)=2.257; p=.098). Further analysis showed that conditions B, C, and D did not differ (m=2.80 (sd=0.919), 2.70 (sd=0.675) and 2.80 (sd=0.632), respectively) and that the stopping distance in these conditions was perceived as neither to close nor too far away. However, the ratings indicated that the robot stopped too far away in condition A (m=3.50, sd=0.850). Thus, we compared condition A to all other conditions and received the following results:

- conditions A and B: T(18)=1.769; p=.094;
- conditions A and C: T(18)=2.331; p=.032;
- conditions A and D: T(18)=2.090; p=.051.

The difference between conditions A and C is statistically significant, while the difference between conditions A and B and conditions A and D are approaching statistical significance. Thus, the participants of condition A were most inclined to wish for a smaller stopping distance between them and the robot. This is in line with the expectation that participants accept the robot to come closer if it communicates its intention during the approach. This partly supports H1. However, according to the hypothesis people should also allow people in condition B to come closer which we did not find. Thus, the results also point to the importance of congruence that we expected in H2.

C. Helpfulness of the robot's functional noise

The mean rating of the helpfulness of the functional noise for all conditions was 3.05 (on a scale of 1 to 5, sd=1.085). A one-way ANOVA showed that the differences between groups approached statistical significance (F(3,36)=2.433; p=.097). The means for the conditions were A: 3.60 (sd=1.174), B: 3.10 (sd=0.876), C: 3.10 (sd=1.197), and D: 2.40 (sd=0.843). However, independent samples T-tests showed that only the difference between conditions A and D was approaching significance (T(18)=1.964; p=.065) which might be due to the fact that the standard deviation in all conditions was quite high. Hence, the participants strongly differed in their perception of the helpfulness of the functional noise even within conditions. However, there is a trend that participants in condition A found the functional noise to be more helpful than those in condition D. Thus, the variation in the level of noise might actually underline the robot's intentions that in condition A were also communicated by accelerating and decelerating. In contrast, if the speed of the robot is not in line with the functional noise or if both of them are constant, their capability to reveal the system's intention seems very limited. Hence, the assumption connected to H1 that the participants would rate the helpfulness of the functional noise higher if it increased and decreased was only partially supported for when it was congruent with the gradient of velocity supporting what we found in the previous section.

D. Users' attitudes toward the robot on the Godspeed scales

We expected to see differences in the users' attitudes toward the robot in their ratings of the Godspeed scales [3]. Table I shows the mean ratings of all its subscales.

1) Anthropomorphism: A one-way ANOVA showed that the ratings of the robot's anthropomorphism differed significantly between the conditions (F(3,36)=5.021; p=.006). We conducted pairwise comparisons to understand the differences in more depths. It turned out that in condition A (m=3.02, sd=0.45) the participants perceived the robot as being significantly more anthropomorphic than in conditions B (m=2.18, sd=0.67) (T(16)=3.145; p=.006) and D (m=2.18, sd=0.54) (T(17)=3.640; p=.002). However, this was not true for condition C. Condition A and C differed in the approach velocity but used the same functional noise. Thus, the functional noise in this case seemed to play an important role in the judgment of the robot's anthropomorphism.

This assumption is underlined by the lack of a significant difference between conditions B and D that also used the same

TABLE I

MEAN RATINGS OF THE GODSPEED SCALES (SD) FOR ALL CONDITIONS

Scale	**Overall**	**A**	**B**	**C**	**D**
Anthropomorphism	2.54 (.68)	3.02 (.45)	2.18 (.67)	2.82 (.68)	2.18 (.54)
Animacy	2.56 (.59)	2.83 (.46)	2.42 (.60)	2.80 (.67)	2.20 (.40)
Likeability	3.54 (.56)	3.78 (.51)	3.33 (.42)	3.62 (.64)	3.42 (.61)
Perceived Intelligence	3.12 (.55)	3.33 (.62)	2.98 (.63)	3.30 (.45)	2.90 (.41)
Perceived Safety	3.73 (.65)	3.70 (.71)	3.60 (.54)	4.00 (.74)	3.63 (.60)

functional noise. Moreover, it is supported by differences in perception of anthropomorphism between conditions B and C and C and D. We observed a trend that the participants found the robot's behavior more anthropomorphic in condition C (m=2.82, sd=0.68) than in condition B (T(16)=2.028; p=.06). Furthermore, the participants' rating of anthropomorphism was significantly higher in condition C than in condition D (T(17)=2.280; p=.036). Thus, overall the functional noise played the major role in attributing anthropomorphism to the robot with the noise with increasing volume at the beginning and decreasing volume at the end being perceived as more anthropomorphic than the constant noise. Thus, in this case the noise played the more important role than the congruency between behaviors.

2) Animacy: The ratings of the robot's animacy showed significant differences between all conditions when we conducted a one-way ANOVA (F(3,38)=3.057; p=.041). Pairwise comparisons revealed that these were actually due to different perceptions of conditions A and D (T(17)=3.199; p=.005) and C and D (T(18)=2.432; p=.026). A (m=2.83, sd=0.46) and C (m=2.80, sd=0.67) were rated as being more animate than D (m=2.20; sd=0.40). However, there was no significant difference between A and C on the one side and B (m=2.42, sd=0.60) on the other. Overall it seems that the perceived animacy was influenced mainly by the intentional sound (compared to the intention-neutral constant sound), however, also the increase and decrease of velocity and, thus, congruency seemed to have some impact on the perception. Constant behaviors as in condition D seemed to be perceived as least animate.

3) Perceived intelligence: Non-significant trends indicated that participants in condition A (m=3.33, sd=0.62) perceived the robot as being more intelligent than participants in condition D (m=2.90, sd=0.41)(T(17)=1.817; p=.087). Participants in condition C (m=3.30, sd=0.45) also rated the robot as being more intelligent than participants in condition D (T(18)=2.058; p=.054). These findings underline the results reported in previous sections that have shown the importance of the functional sound for the perception of the robot.

4) Likeability: A pairwise comparison between conditions A and B regarding likeability showed a trend that was approaching significance (T(17)=2.057; p=.055). Participants in condition A seemed to find the robot more likeable (m=3.78, sd=0.51) than participants in condition B (m=3.33, sd=0.42). The modification between these conditions was only the functional sound. In condition A the sound was congruent with the acceleration and deceleration of the robot's velocity. Condition B contained the same velocity pattern but a constant sound. Thus, for likeability, the inconsistency in condition B might actually have had a negative influence on the ratings which supports H2. However, we did not find that participants in condition A liked the robot better than in all other conditions (including C which was the second inconsistent condition).

5) Perceived safety: No statistically significant differences were found between the groups regarding the perceived safety. Even though we assumed that the inconsistent conditions and particularly the conditions in which the robot did not show early signs of stopping were more threatening to the users, this was not the case. The most obvious explanation for this finding is the small size of the robot. To anticipate this, also the video analysis did not reveal any signs of feeling unsafe in the participants' behavior (see Section V-E). Thus, the size of the robot is one major limitation of the study that will be discussed in Section VI.

E. Video analysis

To enrich the analysis with some objective findings, we analyzed the video data that we recorded during the experiment as specified in Section IV-E. In the following we present our findings regarding gaze direction, gaze shifts, and facial expressions of the users.

1) Gaze direction: In all conditions we found that most gazes were directed toward the robot which is not surprising because in the interval that we analyzed the robot was getting fairly close to the participants and they did not have any other tasks that might have distracted them from paying attention to the robot. It seemed that the participants in conditions B and D (99% and 95%), where the sound was constant and did not convey intention, spent even more time looking at the robot than in conditions A and C (89% and 91%). However, this difference was not statistically significant. One has to keep in mind though that only five seconds of the video were analyzed for each person which equals an overall time of 185 seconds. Nevertheless, we believe that in a bigger corpus the differences might turn out to be statistically significant.

2) Gaze shifts: The analysis revealed that the mean number of gaze shifts per person was significantly higher in condition C (m=1.10, sd=1.29) than in condition B (m=0.11, sd=0.33) (T(17)=2.2; p=.039) and that there was a trend towards a higher mean number of gaze shifts per person in condition A (m=1.3, sd=2.00) than in condition B (T(17)=1.75; p=.097). Thus, in the conditions with the increasing and decreasing volume of the functional noise, the participants more often took the chance to look away from the robot, particularly compared to the condition where functional noise and approach velocity were inconsistent. However, in our data the difference between these conditions and condition D (m=0.63, sd=1.19), where the functional noise and the approach speed were constant, was not statistically significant even though the means looked different at first view. Again we believe that this is due to the small dataset and the results could be clearer in a larger-scale analysis.

3) Facial expressions:: Finally, we analyzed the facial expressions of the users by categorizing them into two categories that we identified in a qualitative analysis: smile and neutral expression. A Chi square test revealed that there were actually differences in the mean time that the people smiled at the robot in the different conditions (X^2(3, N=53)=9.79; p=.02). Participants in condition A smiled more (m=3.2 seconds, sd=2.27) than in the other conditions where they more often had a neutral expression (particularly in condition B (m=1.59 seconds, sd=2.15)). This finding is in line with the questionnaire results where the participants indicated that the robot in condition A was most likeable.

All our findings reported in this section only partially support hypothesis H2 that the congruency in robot behavior will cause a more positive attitude in the users. This was only found to be true if the robot's behavior did also communicate intent. Thus, the participants overall seemed to have the most positive attitude toward the robot in condition A.

VI. LIMITATIONS AND CONCLUSIONS

A. Limitations of the experiment

The experiment suffered from some limitations that have already been mentioned at different points of the paper. Probably the biggest limitation was the small size of the robot. Due to this, participants in all conditions perceived the robot as being save even though it approached them to a distance of just 25cm. Particularly with respect to perceived safety of the robot, we expect that a larger robot would have yielded different results. Thus, future research aims to reproduce the study with a larger robot. Another issue with the robot was that it made some motor noise that might have interfered with the functional noise that was added to the system. This noise cannot be avoided and we tried to make the functional noise louder than the motor noise. In future research we will need to check how both were actually perceived by the participants.

Some limitations concern the design of the experiment and the data analysis. One of these issues was that in the conditions with the constant speed the robot would need some time to accelerate and to stop. We kept this time as short as possible and it was much shorter than in the other conditions. However, the results might have been influenced by this limitation. Finally, the interaction itself was really short just consisting of the approach and, thus, also the set of data that we analyzed was rather small. While this might limit the explanatory power of the study, we felt that we had to limit the interaction to the approach to not introduce any confounding factors that might arise from any other behaviors that the robot produces.

B. Conclusion and implications for robot design

Even though the study has certain limitations, it allows us to draw some useful conclusions for future robot design. All our findings support the fact that participants had the most positive attitude toward a robot that communicated its intentions and did so in a way that was congruent across modalities (audio/visual) compared to robots that did not communicate intentions or communicated them in incongruent ways. In our experiment we further found that the functional noise was even more important for the perception of the robot and the interpretation of its behavior than the driving behaviors which points to the immense difference that the creative design of functional noise can make for robots.

REFERENCES

[1] K. Albrecht. *Social Intelligence*. Wiley, 2006.

[2] N. Ambady and J. Skowronski. *First Impressions*. Guilford Press, 2008.

[3] C. Bartneck, D. Kuli, E. Croft, and S. Zoghbi. Measurement instruments for the anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety of robots. *International Journal of Social Robotics*, 1:71–81, 2009.

[4] J. T. Butler and A. Agah. Psychological effects of behavior patterns of a mobile personal robot. *Auton. Robots*, 10(2):185–202, Mar. 2001.

[5] K. Dautenhahn, M. Walters, S. Woods, K. L. Koay, C. L. Nehaniv, A. Sisbot, R. Alami, and T. Siméon. How may i serve you?: a robot companion approaching a seated person in a helping context. In *Proc. of the 1st ACM SIGCHI/SIGART conference on Human-robot interaction*, HRI '06, pages 172–179, New York, NY, USA, 2006.

[6] M. J. Gielniak and A. L. Thomaz. Generating anticipation in robot motion. In *20th IEEE International Symposium on Robot and Human Interactive Communication, RO-MAN 2011, Atlanta, Georgia, USA (RO-MAN 2011)*, pages 449–454, 2011.

[7] E. Hall. *The hidden dimension*. Doubleday, 1966.

[8] J. Ham, M. van Esch, Y. Limpens, J. de Pee, J.-J. Cabibihan, and S. S. Ge. The automaticity of social behavior towards robots: The influence of cognitive load on interpersonal distance to approachable versus less approachable robots. In *Proc. 4th International Conference on Social Robotics (ICSR)*, pages 15–25, 2012.

[9] G. Hoffman. Anticipation in human-robot interaction. In *AAAI Spring Symposium: It's All in the Timing*, 2010.

[10] K. Isbister and C. Nass. Consistency of personality in interactive characters: verbal cues, non-verbal cues, and user characteristics. *Int. J. Hum.-Comput. Stud.*, 53(2):251–267, 2000.

[11] L. Langeveld, R. van Egmond, R. Jansen, and E. Özcan. Product sound design: Intentional and consequential sounds. In D. Coelho, editor, *Advances in Industrial Design Engineering*. InTech, 2013.

[12] C. Lichtenthäler, T. Lorenz, and A. Kirsch. Influence of legibility on perceived safety in a virtual human-robot path crossing task. In *Proc. 21st IEEE Int. Symposium on Robot and Human Interactive Communication (RO-MAN 2012), Paris, France*, pages 676–681, 2012.

[13] M. Lohse. Investigating the influence of situations and expectations on user behavior: empirical analyses in human-robot interaction. *Doctoral Thesis. Bielefeld University, Technical Faculty, Germany*, 2010.

[14] B. Mutlu, F. Yamaoka, T. Kanda, H. Ishiguro, and N. Hagita. Nonverbal leakage in robots: communication of intentions through seemingly unintentional behavior. In *Proceedings of the 4th ACM/IEEE international conference on Human robot interaction*, HRI '09, pages 69–76, New York, NY, USA, 2009. ACM.

[15] S. Nonaka, K. Inoue, T. Arai, and Y. Mae. Evaluation of human sense of security for coexisting robots using virtual reality. 1st report: evaluation of pick and place motion of humanoid robots. In *Proc. IEEE International Conference on Robotics and Automation (ICRA '04)*, volume 3, pages 2770–2775 Vol.3, 2004.

[16] U. D. of Transportation: National Highway Traffic Safety Administration. Technical report, 2009.

[17] A. Sardar, M. Joosse, A. Weiss, and V. Evers. Don't stand so close to me: users' attitudinal and behavioral responses to personal space invasion by robots. In *International Conference on Human-Robot Interaction, HRI'12, Boston, MA, USA*, pages 229–230, 2012.

[18] S. Satake, T. Kanda, D. F. Glas, M. Imai, H. Ishiguro, and N. Hagita. How to approach humans? strategies for social robots to initiate interaction. In *Proc. 4th ACM/IEEE int. conference on Human-Robot Interaction*, HRI '09, pages 109–116, New York, NY, USA, 2009.

[19] L. Takayama, D. Dooley, and W. Ju. Expressing thought: improving robot readability with animation principles. In *Proceedings of the 6th international conference on Human-Robot Interaction*, HRI '11, pages 69–76, New York, NY, USA, 2011. ACM.

[20] R. van Egmond. The experience of product sounds. In H. Schifferstein and P. Hekkert, editors, *Product Experience*, pages 69–89, Amsterdam, Netherlands, 2007. Elsevier.

[21] M. L. Walters, K. Dautenhahn, S. N. Woods, and K. L. Koay. Robotic etiquette: results from user studies involving a fetch and carry task. In *Proc. of the ACM/IEEE international conference on Human-Robot Interaction*, HRI '07, pages 317–324, New York, NY, USA, 2007.