The Influence of Transparency and Adaptability on Trust in Human-Robot Medical Interactions

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Abstract— **In this paper, we present a study in which we test the influence of the two variables transparency and robot adaptability on people's trust in a human-robot blood pressure measuring scenario. While our results show that increased transparency, i.e. robot explanations of its own actions designed to make the process and robot behaviors and capabilities accessible to the user, has a consistent effect on people's trust and perceived comfort, robot adaptability, i.e. the user's opportunity to adjust the robot's position according to their needs, does not influence users' evaluations of the robot as trustworthy. Our qualitative analyses indicate that this is due to the fact that transparency and adaptability are complex factors; the investigation of the interactional dynamics shows that users have very specific needs, which need to be met by the robot.**

I. INTRODUCTION

In a healthcare scenario in which the robot takes over routine medical tasks such as heart rate and blood pressure measurement, trust into the system plays an important role. Previous work (e.g. [Schaefer et al., 2016]) has identified several factors that influence trust; for instance, the system's performance, such as reliability, false alarm and failure rates [Hancock et al., 2011] plays a role, but also the way the system is introduced [Ximenes et al., 2014], as well as particular functionalities of the system, like its anthropomorphism, transparency, ease of use and politeness ([Schaefer et al., 2016]) .Choi and Ji (2015) suggest that trust depends on three factors [Choi and Ji, 2015, page 699]:

- system transparency
- technical competence
- situation management

Transparency is a means to make users understand the human-robot interaction situation and the robot's capabilities [Lyons, 2013]. Transparency can be communicated in many ways, for instance, via speech, sound, or images, where speech is the most natural form of communication among people (cf. [Sanders et al., 2014]). Transparency has so far been addressed in few studies [Schaefer et al., 2016], and with rather inconclusive results (see [Sanders et al., 2014]). Technical competence, in contrast, has been addressed in numerous studies (see [Hancock et al., 2011]), and since it is always optimized for, it provides the least grounds for optimization during human-robot interaction. Situation management is mostly concerned with people feeling in control of the situation; concerning our blood pressure measurement situation, this may mostly relate to the ways in which the user can adjust the robot to accommodate to his or her personal needs best. Thus, of the three factors identified by Choi [Choi and Ji, 2015], transparency and adaptability are the two factors that seem to be most promising. In their meta analysis of the literature on trust in automation, Schaefer et al. (2016) explicitly identify communication and transparency as an area where more research is needed. At the same time, their meta analysis indicates that adjustability of the system should increase users' trust [Schaefer et al., 2016]. This leads to the following three hypotheses to be tested in this paper:

H1 Applying transparency by explaining current and future actions during the blood pressure measurement procedure has a positive impact on the users' evaluation of the robot. Informing the participant of imminent actions ("I am going to come closer"), limitations of the robot ("Please tell me when you are done"), and status of extended actions ("I am almost finished") is expected to increase users' trust as they know what is happening [Lyons, 2013].

H2 Applying adjustment by giving the user the option to influence the position of the blood pressure measurement cuff has a positive impact on the users' evaluation of the robot. Giving participants the opportunity to influence the actions of the robot is expected to make them feel more in control of the situation, which should lead to increased trust [Schaefer et al., 2016].

H3 Applying both transparency and adjustment has an even more positive impact on the users' evaluation of the robot. It is expected that letting the participant influence the robot's actions (as in H2) and providing more clarity of the robot's actions (as in H1) will make the participant trust the robot even more than either of the two factors alone.

II. METHODOLOGY

We address the three hypotheses outlined above using a between subject design.

A. Conditions

The experiment comprises four conditions (outlined in table I), which are specified as follows:

1) Transparency: [Lyons, 2013] provides an extensive analysis of transparency, taking a very broad approach that comprises both robot-to-human transparency, which includes

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	No Transparency	Transparency
No Adjustment	Condition 1	Condition 2
Adjustment	Condition 3	Condition 4

TABLE I

THE FOUR CONDITIONS AS TABLE

communication about the robot's intentional, task, analytical and environmental model, and robot-of-human transparency, which includes communication about the robot's awareness of the human's current states and a model of the kind of teamwork targeted. Correspondingly, Lyons criticizes studies in which "novice users are asked to interact with the robotic systems for a brief duration," because in such short interactions, the need for the kind of deep transparency he suggests does not become apparent. While this is absolutely convincing for close, long-term human-robot collaboration, in the current scenario, brief interactions with novice users are actually realistic. In particular, the robot is intended to drive through a care facility and to take over routine medical measurement tasks on a large number of patients and care receivers (see [Fischer et al., 2015]). Thus, the kind of transparency relevant for this scenario concerns that participants understand the robot's next action, its limitations and its current status.

In conditions 1 and 3, the robot offers enough information to enable the participant to complete the experiment. In conditions 2 and 4, however, the robot announces all major actions to create more transparency for the participant. For instance, the robot checks the readiness of the participant and then describes its next actions, such as "I am going to come closer now", or "I am going to adjust the height of the cuff based on your body height". This is done throughout the experiment:

- Before the robot moves to its measuring position next to the participant
- Before folding out the arm
- Before the automatic adjustment of the height of the cuff, based on user height
- Before the potential adjustment of the height of the cuff, based on user input
- Before folding in the arm again

2) Adjustment: In conditions 2 and 4, the robot is adjusting its position to the user's needs. The possibility to adjust the robot is supposed to give the participant a feeling of control over, and influence on, the actions of the robot. First, the way the robot approaches the participant is adjusted; while the robot in the non-adjustment conditions 1 and 2 moves with constant speed, in the adjustment conditions 3 and 4 it moves forward, then turns to face the participant, and then continues with a lower speed. This is supposed to give the participant the feeling that his or her presence has an influence on the robot.

Second, after the user has attached the cuff to his or her arm, the user is asked whether or not the current position is comfortable. If this is the case, the experiment will continue, if not, the participant is asked to say whether the arm should be moved up or down. This gives the participant some control over the robot. Since, for reasons of comparability, the adjustment is not supposed to actually make the cuff position more comfortable than it is in conditions 1 and 2, the adjustment is limited to approximately 2cm. This is enough to be clearly noticeable, yet not enough to make a significant difference in the level of physical comfort.

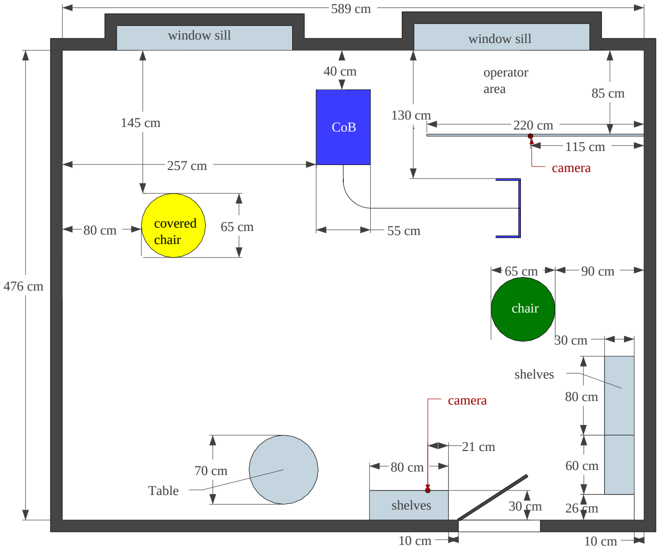

Fig. 1. The layout of the room in which the experiments took place. The participant is seated in the chair marked in green, the starting position of the robot (CoB) is presented as a blue rectangle, its final position is marked in blue, and the cable of the robot was moved around a chair marked in yellow.

B. Procedure

The experiment comprises three parts: a pre-experimental questionnaire, the experiment proper, which is video recorded, and a post-experimental questionnaire.

1) The first questionnaire: The first questionnaire was filled in at the place where the participant was recruited, so that the participants could not hear the robot before the experiment. This questionnaire starts out with four questions concerning users' consent regarding the obtained video footage. People who did not agree to be filmed at all could not take part in the experiment and were allowed to leave immediately. The other three questions address the use of the videos in a thesis, in publications and at conferences. The following questions elicit demographic background information, including age, gender, height, and disciplinary background, as well as participants' experience with autonomous robots and with blood pressure measurement.

2) The experiment proper: The experiment proper is conducted in a lab. Participants are guided to the door once the operators inside are ready, and the participant then enters the room alone, unaware of the two operators who are hidden behind partition walls. The layout of the room is shown in Fig. 1.

As soon as the participant enters the room, the operators activate the first sequence of the robot program and the experiment proper takes place. During the experiment, two cameras are recording video footage so that the operators can activate different sequences of the robot program at the appropriate time, according to the Wizard-of-Oz approach [Weiss et al., 2009]. The cameras are placed on the shelves to the left of the door and on the partition wall in front of the operator space in the top right corner of the room.

The experiment proper can be divided into several phases.

- **Entrance:** When the participant enters the room, the robot welcomes the participant and asks him or her to take a seat. Once the participant confirms that he or she is seated, the robot announces its approach (in conditions 2 and 4). In all conditions, the robot approaches the participant then, stopping next to the user.
- **Preparation:** In conditions 2 and 4, the robot announces its arm movement. Then the robot folds out the arm with the cuff and adjusts its height, with or without an announcement, depending on the condition. In all cases, the height of the cuff is adjusted to the height of the participants:
  - Participants shorter than 170 cm have a low setting;
  - participants between 170 and 180 cm have a medium setting;
  - participants taller than 180 cm have a high setting.

  After this standard adjustment, the robot asks the participant to attach the cuff to his or her right arm. The participant is asked to tell the robot when he or she is ready. In conditions 3 and 4, the robot then asks whether or not the participant is comfortable, and depending on the participant's answer, the robot will adjust the height of the cuff. As condition 4 combines both transparency and adjustment, this further adjustment is here again announced prior to the movement.
- **Measurement:** The robot announces the start of the measurement, and the operator activates the blood pressure measuring device. In conditions 2 and 4, the robot adds how the measurement takes place and informs the user, once the cuff is fully inflated, that the measurement is almost done.
- **Exit:** After the measurement, in conditions 3 and 4, the robot asks the participant whether or not to adjust the height of the cuff to allow for an easier exit. If the user accepts the offer, the robot may announce the movement (in condition 4) before adjusting the height of the cuff. Regardless of condition, the robot finally asks the participant to remove the cuff and wishes the participant a nice day. He or she then exits the room.

Most experiments took around three and a half minutes from the participant entering until him or her leaving the lab. The actual measurements took around one and a half minutes.

Once the participant leaves the room, he or she is handed the second part of the questionnaire.

3) Second questionnaire: The second questionnaire consists of 21 questions about the participant's perception of the robot concerning likeability, trust, comfort, predictability, being sensed by the robot, control and reliability, among others. For instance, we used semantic differentials, asking participants to rate their impressions of the robot on a 7-point scale, where 1 corresponds to, for instance, *responsible* and 7 to *irresponsible*. To avoid that the participants answered the questions mechanically, the scales were reversed for every other question. This means that instead of always having positive attributes on one side, the scales alternate so that the user has to be more alert while answering.

Upon finishing the second questionnaire, the participants were rewarded with chocolate for their participation, debriefed and released from the study.

C. Participants

85 students and staff from the University of Southern Denmark at Odense participated in the experiment. For several reasons, some participants had to be excluded (see below), leaving 63 participants in total. Of the 63 remaining participants, 49 identified as male and 14 identified as female. The age ranged between 20 and 64 years with a mean of 29.52 years (standard deviation 9.697). Participants ranged from 157 cm to 196 cm in height, with a mean of 178.76 cm and a standard deviation of 8.734. All participants were compensated for their time with a bar of chocolate.

D. Robot

For the experiments, a robot was needed that fulfils the following criteria:

- **Size**: The robot has to be large enough to reach the upper arm of a sitting person;
- **Features**: The robot has to have movable arm to reach the user with the cuff of the blood pressure measuring device;
- **Robustness**: The robot has to be robust enough to withstand any force a user might exert on it during the measurement. This includes not tipping over when the robot arm is folded out and the cuff is attached to the user;
- **Mobility**: The robot has to be able to move across the room to reach the user at a predefined position;
- **Communication**: The robot has to be able to speak in order to communicate with the user efficiently and in a way that is natural to the user;
- **Control**: The robot has to have remote control features so that the Wizard-of-Oz approach is possible.

Based on these criteria, the Care-O-Bot 3 was chosen for the experiment ([Fraunhofer IPA, 2017]). Additionally, a conventional blood pressure measuring device, a BM 58 ([Beurer, 2009]), was attached to the robot arm to measure the blood pressure. The tube between the cuff and the device was extended to allow the operator to start the measurement without the participant's direct involvement.

III. RESULTS

During the three-week testing period, 85 participants were tested; however, some participants had to be excluded from the analysis, see below.

	No Inflation	Inflation	p-value
Intimidating	4.56	2.96	0.001
Trustworthy	4.13	5.51	0.004
Condition	3.13	13	0.007
Experience	3.25	4.35	0.013
Unreliable	3.81	2.43	0.016
Likelihood of use	3.94	5.28	0.027
Trust	4.25	5.30	0.036
Time of day	13.75h	12.87h	0.046
Irresponsible	3.38	2.39	0.057
Prediction	4.19	5.17	0.083
Unfriendly	2.75	2.01	0.098

TABLE II

STATISTICAL RESULTS FOR INFLATION

	No Restart	Restart	p-value
BP Frequency	2.06	1.20	0.007
Unfriendly	2.05	1.20	0.008
Polite	5.98	6.80	0.010
BP Execution	2.92	4.20	0.023

TABLE III

STATISTICAL RESULTS FOR RESTARTS

Comfort	Cond. 1	Cond. 2	Cond. 3	Cond. 4
Cond. 1	-	0.277	0.767	0.080
Cond. 2	0.277	-	*0.030*	0.825
Cond. 3	0.767	*0.030*	-	*0.007*
Cond. 4	0.080	0.825	*0.007*	-

TABLE IV

P-VALUES FROM POST HOC TESTS FOR LEVELS OF COMFORT; SIGNIFICANT LEVELS ARE IN ITALICS

A. *Evaluation of the Experiments*

During the experiments it was found that several participants failed to close the cuff properly, which prevented the cuff from being inflated. Since the robot could not react to that and just continued as if the cuff had been inflated, we tested whether this failure influenced participants' evaluations of the robot. A total of 16 failed inflations were found, compared to 69 successful inflations. An independent samples T-Test with equal variances not assumed was performed to determine the effect of never inflated cuffs. The results can be found in table II. They show that participants who did not experience inflation had significantly less experience with blood pressure measurements. This may indicate that explanations about how to apply the cuff were insufficient.

Furthermore, as expected, participants who did not experience inflation of the cuff trusted the robot significantly less, found it more unreliable and more intimidating. They had a significantly lower intention of using the robot again and found it more irresponsible. In addition, near significant differences were detected concerning participants' ability to predict the robot's actions, which was lower without inflation, and their evaluation of the robot's unfriendliness.

Based on these findings, participants who experienced failure concerning the inflation of the cuff were excluded from further analysis. In addition, one participant was excluded since he sabotaged the experiment by walking around and not interacting with the robot.

Of the 68 remaining participants, five experienced restarts; in order to determine the effect of restarts, another independent samples T-Test was conducted (see table III). The test reveals that the group of participants who experienced restarts found the robot significantly less unfriendly and more polite. In addition, participants who experienced restarts had their blood pressure measured significantly less frequently and by different people. Because restarts did have an effect on the participants' evaluation of the robot, these participants were excluded from the further analysis as well.

This leaves 15 participants for condition 1, 20 participants for condition 2, 15 participants for condition 3, and 13 participants for condition 4, amounting to 63 participants in total.

B. *Analysis*

In order to determine whether or not the three hypotheses should be rejected, an analysis by condition was conducted.

In order to ensure that a fair distribution of participants was established, a one-way ANOVA was conducted on age, gender and all other background factors. No significant differences were found for any condition, which suggests that no condition had a disproportionate amount of specific participants.

Afterwards, a one-way ANOVA was performed on the participants' evaluation of the robot in the second questionnaire. Significant results concern perceived comfort (p = 0.004), and the evaluation of how much participants trusted the robot is near-significant (p = 0.058).

A Post-Hoc Tukey test reveals that both conditions with transparency were perceived as significantly more comfortable than the adjustment condition. In condition 4, in which the robot exhibited both transparency and adjustment, the robot was experienced as slightly more comfortable than in condition 1 (see table IV).

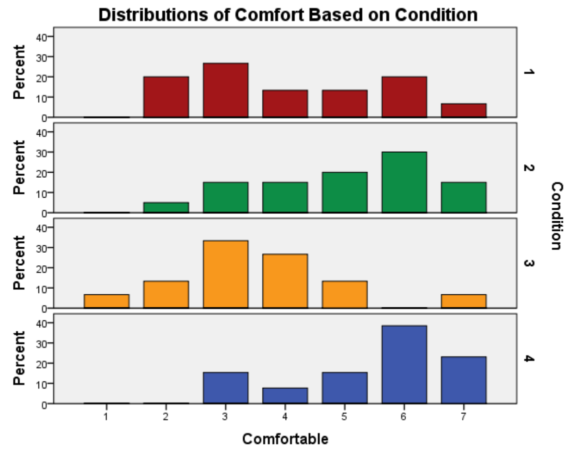

Fig. 2. Distribution of participants' evaluation of how comfortable they were during the experiment

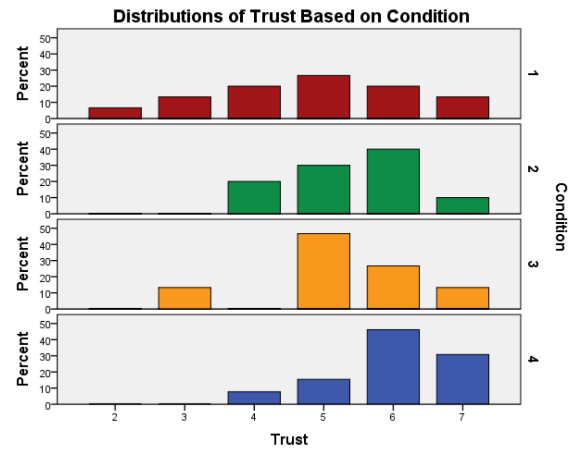

Fig. 3. Distribution of participants' evaluation of how much they trusted the robot

	No Transparency	Transparency	p-value
Comfortable	3.80	5.18	0.001
Prediction	4.73	5.55	0.018
Trustworthy	5.17	5.79	0.020
Trust	5.03	5.64	0.046
Like	5.00	5.58	0.083

TABLE V

STATISTICAL RESULTS FOR TRANSPARENCY

	Not Combined	Combined	p-value
Trust	5.18	6.00	0.013
Comfortable	4.28	5.46	0.016
Control	2.94	3.92	0.066

TABLE VI

STATISTICAL RESULTS FOR COMBINED TRANSPARENCY AND ADJUSTMENT

Considering trust, the post hoc test shows that people trusted the robot more in condition 4 than in condition 1 (p = 0.035). No other factors apart from trust and comfort caused significant or near significant differences between the conditions.

1) The Effects of Transparency: In order to identify the effects of each factor under consideration, the three conditions were evaluated as a two-case problem; for transparency, this means that 30 participants experienced no transparency while 33 participants did. For these two groups, an independent samples T-Test with equal variances not assumed was performed.

Significant and near significant findings can be seen in table V. The findings indicate that participants found the robot significantly more trustworthy, and they also personally trusted the robot more with transparency. They thought they could better predict the robot's actions and were much more comfortable with transparency. The difference between the average levels of comfort was found to be 1.38 points, suggesting that transparency is a major factor in increasing people's comfort levels during the experiments. Furthermore, participants show a tendency to like the robot better with transparency. This suggests that hypothesis H1 is confirmed.

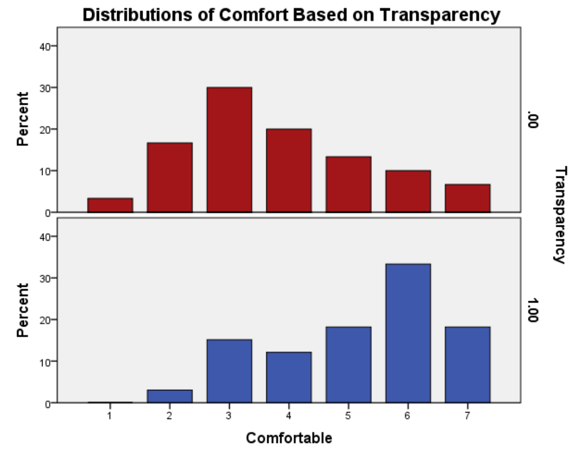

Fig. 4. Distribution of levels of comfort, for transparency-wise split

2) Effects of Adjustment: Merging the data into two conditions regarding transparency means that 35 participants experienced no adjustment while 28 did. However, not a single parameter was found to have significant or near significant effects. This means that hypothesis H2 cannot be confirmed.

3) Effects of Transparency and Adjustment Combined: Merging conditions 1 through 3 together to form a two-case problem, with 50 participants not experiencing the combination of transparency and adjustment, and 13 participants experiencing it, reveals significant differences regarding trust and comfort and near-significant differences regarding the feeling of being in control (see table VI). Based on these results, hypothesis H3 should not be rejected.

C. Qualitative Analysis

In the qualitative analysis, the obtained video footage and the comments participants made in the second questionnaire were scrutinized for interaction quality and interaction problems.

1) Verbal Communication: The analysis shows that not everyone was comfortable to interact with the robot via speech. Several participants did not talk to the robot initially but talked to it later, whereas one person never spoke to the robot.

Furthermore, the robot clearly did not speak enough. One person from condition 1 mentioned *”I would maybe have been more calm if the robot have talked more about what he is doing next [...]”(sic)*, which is in line with the quantitative findings showing that transparency is important. The same person also wrote asked that the robot *”[...] maybe talked to me while he was measuring my blood pressure”*. Even in the transparency conditions, the robot only made one comment during the measurement, which participants found to be too little for an interaction of one and a half minutes, as their comments show; they would have preferred *"assurances that nothing can go wrong"* and *"some small talk like >only 10 more seconds< or >well done<"*.

2) Robot Adjustment: Participants' post-experimental comments reveal that the robot did not adjust enough in the adjustment condition, which left some participants in an uncomfortable position. Furthermore, the videos show that people did not want to adjust the way the robot offered to adjust the cuff. Some people changed their minds about wanting to adjust, so the robot forced an adjustment onto them, as it could not abort a started process. Other people wanted adjustment in other directions than the ones offered. One participant changed his mind once he heard that the robot wanted to adjust the height, another one was fine with the adjustment, as long as his arm was not attached to the robot.

IV. DISCUSSION AND CONCLUSION

The results of our analysis show that 'transparency', i.e. the robot providing information about its current and future actions, has an effect on people's perceived comfort and trust into the robot. However, given participants' post-experimental comments and the analysis of the videos, this effect may actually due to the fact that the robot was speaking more in general. This is in line with work by [Sanders et al., 2014], who also found continuous feedback to increase trust. Since an interaction with long sequences of silence is very unusual in human interaction (e.g. [Levinson, 1983]), the simple fact that the robot was talking at all may have comforted participants. A future study should thus address whether the contents of the robot's utterances matters.

Regarding robot adjustability, hardly any effects could be found, in contrast to previous findings; Choi and Ji [Choi and Ji, 2015] used a questionnaire to back up their results, not actual experiments, so that there may be a discrepancy between expected effect and real effect. Regarding other studies that report increased trust due to some level of cooperation (cf. [Schaefer et al., 2016]), the adjustments the robot could make in our study may have simply not been sufficient in order to provide participants with a feeling of being in control; more directions and faster response to participants' requests as well as the ability to abort a process at the moment at which the participant asks for it, seem to be mandatory in order for people to experience the robot as adaptable.

To conclude, we found a considerable effect of transparency on users' trust in a human-robot medical measurement scenario, whereas the possibility to make limited adjustments did not influence users' evaluations of the robot. In the brief interactions in this setting, users profited from information about the robot's next actions, current state and limitations, yet it cannot be ruled out that this effect is at least partially due to the fact that the robot produced more verbal actions and thus created more social presence. Transparency and adjustability are thus not simple, binary variables that are either there or not; instead, they have to match users' specific needs in order to influence users' trust into the robotic system.

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