Effect of variable motion behavior of a mobile robot on human compliance in human-robot spatial interaction

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Abstract. This study investigates the effect of variable motion behavior of a mobile robot on human compliance in human-robot spatial interaction at bottlenecks. The robot's behavior is varied in two ways: Either a back-off movement is performed to communicate the intention of yielding priority to a pedestrian. Or in the other cases, the robot passes the bottleneck despite possible interference with a pedestrian, and thus, takes priority over the pedestrian. In an experiment, compliance of a baseline group of participants that experience consistent back-off behavior is compared to a group that experience variable robot behavior including both movement variations. Participants can choose to comply with the robot's action request or to act reactant. Results show no significant differences in objective compliance due to the robot's variable behavior, however, subjective trust of participants is lowered.

Keywords: compliance, human-robot spatial interaction

1. Introduction

To feasibly implement robots in everyday life, the robots' efficiency is a fundamental economic requirement. On one hand, in urgent situations or to ease coordination occasionally, mobile robots therefore need to neglect strict constraints of social spaces and move first and in front of pedestrians. On the other hand, in cases with a higher time budget, robots can act politely and let pedestrians pass first. We assume that humans do not attribute the same scope of action to robots as they do to humans (Sebanz & Knoblich 2009). Hence, It is unclear how pedestrians react to variable robot behavior. The proposed variability might foster confusion or decrease trust and compliance in a robot.

While robot behavior may influence the human subjective reactions (Reinhardt et al. 2017), the effect cannot be directly mapped to behavioral outcomes. In contrast to results of commonly applied questionnaires to measure perceived likeability, intelligence, or perceived safety (Bartneck et al. 2009), actual outcomes of peoples' actions might differ. The theory of cognitive dissonance can be taken as an explanation for this (Harms et al. 2019). There appears to be a lack of studies that investigate actual outcomes of people's actions towards robots. We should therefore design for behavioral compliance rather than for subjective likeability and trust only. On that score, the degree to which an actor follows the acts suggested by a technical system (Meyer & Lee 2013; Vashitz et al. 2009) can give us an objective measure on how humans actually decide to work with a technical system. In the presented study, we aim to investigate the effect of variable robot behavior on human compliance and how this relates to compliance with merely repetitive robot behavior.

In general, previous research suggests that submissive robot motion can foster human trust. In order to achieve that, at first, a pedestrian has to be aware of the robot while walking in its proximity (Harms et al. 2019), and secondly, motion has to be legible to communicate intentions reliably (Dragan et al. 2013). A human-inspired back-off maneuver (Moon et al. 2013) achieved good results in communicating the intention of yielding priority and increased trust (Reinhardt et al. 2017).

Besides the economic need for a “robot first” behavior, dominance is a key part of social expression as it can be used to resolve conflicting goals (Li et al. 2019). It might facilitate human-robot spatial interaction in the case that one actor has to partly recess from an own planned goal or trajectory (Hoc 2001). Li et al. (2019) found differences in how a robot’s status is perceived when it uses purported high-status motion compared to when it uses low-status motion patterns. Hence, the motion strategy of a robot can influence how people perceive its social status, which might help to shape people’s expectations and behaviors. The hypotheses of this paper accordingly formulate to: $H_{1/1}$: Variable robot behavior influences compliance with the robot; $H_{2/1}$: Variable robot behavior influences subjective trust in the robot.

To compare behavioral outcomes we propose a human-robot compliance model where compliance is the aware outcome of three steps, when an action request is given from a robot to a pedestrian (see figure 1). First, the pedestrian has to be aware of the robot so the request can be perceived, secondly, it must be interpreted correctly, and thirdly, it must be acted on as requested by the system. If a pedestrian reacts to the back-off behavior by accepting its underlying intention, and walks ahead of the robot, the human acts compliant. The pedestrian acts reactant if he/she chooses to keep out of the way of the robot. An encounter between human and robot can accordingly be classified as a result of unawareness, wrong interpretations about the robot’s intention, compliance or reactance, referring to an aware decision to act contrary to the robot’s intention.

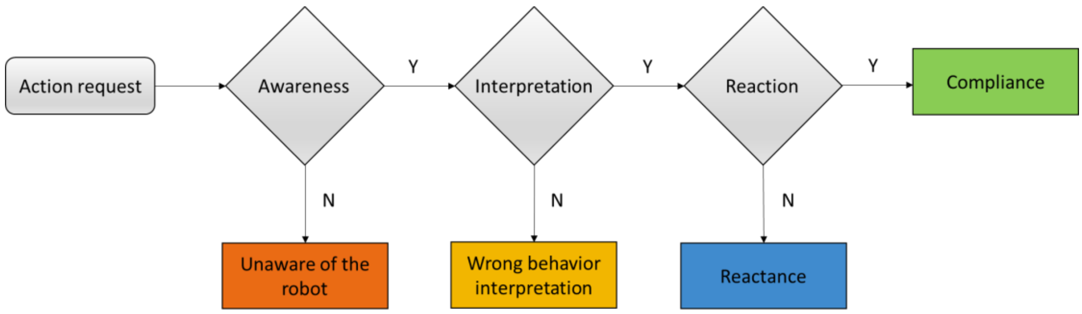

Figure 1. *The human-robot compliance model aligns the consecutive steps action request, awareness, interpretation and human reaction in a flow-chart. Human reactions can thus be classified as being unaware of the robot’s actions, wrongly interpreted robot behavior, conscious reactance or compliance.*

2. Method

2.1 Scenario

The study encompasses the interaction between a mobile robot and a pedestrian at a bottleneck (see figure 2). A study space was set up in the motion lab of the Chair of Ergonomics at the Technical University of Munich. Obstruction walls were used to build two bottlenecks (passage width of standardized doors of 0.95 m (DIN 18040-1)) hindering the participant's path from a start to an end position. Before the encounter, the participant could not see the robot, which prevented the use of an early adaption strategy and thus, a cooperative situation occurred at the bottleneck A. The visual barrier ended at a distance of 1.15 m in front of the bottleneck. Here, the participant could choose between moving through bottleneck A or B. When choosing to move through B, the participant can pass the obstacles and reach the end position without having to interact with the robot. However, path B is longer and should thus result in higher perceived cost.

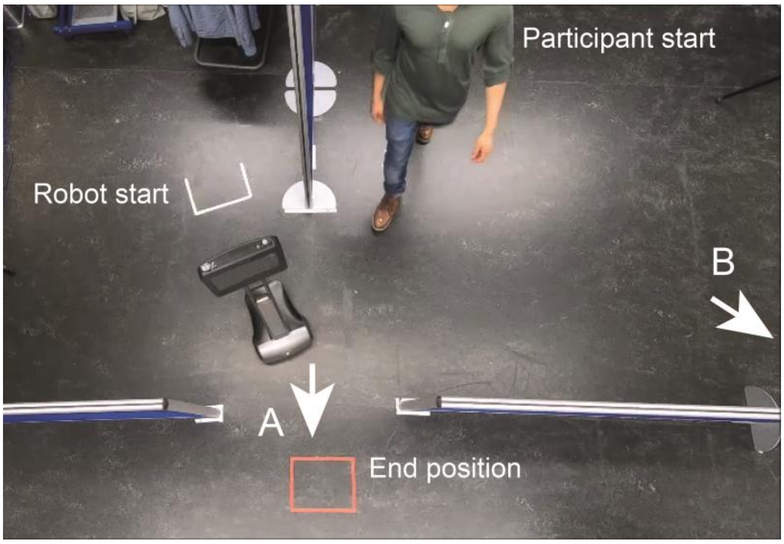

Figure 2. *Experimental space: Participant and robot are separated by a visual obstruction (middle), bottleneck (A) is formed in between two obstructive walls (bottom), where the human-robot encounter is planned. A second bottleneck (B) allows for a longer passage of the obstacles without interacting with the robot.*

2.2 Procedure

The procedure is designed to allow that human and robot arrive at the bottleneck roughly at the same time. Participants are told to walk at natural walking speed and that they can choose to pass through bottleneck A or B to reach the end position. When participants start walking, the robot (BEAM: 1.34 m x 0.22 m x 0.42 m, 17.7 kg) also moves towards A. The robot behavior is varied in two ways: The robot can yield priority to the human by performing a back-off maneuver, or it can take priority by moving through the bottleneck A. In the back-off maneuver, the robot comes to a stop in front of the bottleneck and then drives backwards for three seconds, reaching a back-off distance of approximately 0.5 m. For the dominant behavior the robot drives through the bottleneck without stopping. In one experimental group that experiences consistent (C) behavior, the robot always shows a back-off in all six trials. In the group that experiences variable (V) behavior, the robot shows the back-off in trials one, two, four, and six. In trials three and five, the robot moves through A in a dominant manner.

2.3 Measures

Objective compliance is observed by counting the behavior of the participants according to the model in figure 1. By analyzing the video recordings, the experimenter decided if an interaction occurred and if the participants were aware of the robot. Timing of each single interaction was classified into the participant arriving at the door (-2) much too early, (-1) too early, (0) optimal, (+1) too late or (+2) much too late. If the participant was at the bottleneck so early that the robot arrived afterwards (-2), the encounter was rated as unaware. If the participant was at the bottleneck so late that the robot had already performed the back-off movement before the arrival of the participant (+2), the encounter was rated as unaware likewise. Participants were classified aware for cases -1, 0 and +1, where slightly early and late arrival of participants were noticeable, however, video analysis shows that participants were aware of the movement behavior e.g. by directing gaze at the robot.

The interpretation of the robot behavior was analyzed during the experiment via a questionnaire verbally presented after each trial by means of two legibility-questions: “What was the robot’s intention at the bottleneck?” and “What information do you derive that from?”. At least one of these questions had to be answered in a way that allows to conclude that the participant understood the yielding of priority, to account that legibility was accomplished.

Participants who went through bottleneck A while being aware of the robot and inferring the intention of yielding priority in back-off trials were rated as reacting compliant. They were classified reactant if they decided to pass through bottleneck B. In cases where the robot took priority, a participant’s passage through bottleneck A was classified as reactant and passing through bottleneck B as compliant behavior.

Additionally, participants are asked two items, “do you trust the robot?”, and “can you rely on the robot?” from the trust in automation (TiA) questionnaire (Körber et al. 2019), verbally after each encounter. Resembling the subscale trust, arithmetical means of the two items’ likert-scores ranging from 1 - 5 were calculated and interpreted as a measure for subjective trust.

2.4 Sample

The sample consisted of 76 participants (24 (31.58%) female), age ranging from 19-51 years, with a mean age of M = 23.87 years (SD = 7.27 years), acquired at the university campus. The sample was split into two equally sized groups C and V. Participants received no payment and did not suffer from any movement disorders or other mobility limitations. The study was accepted by the ethical commission of the Technical University of Munich.

3. Results

Figure 3 shows the resulting classified human reactions to the encounter with the robot. A chi-square test compares the C and V group in trial two, indicating no significant initial differences regarding the distribution of reactions ($X^2(3, N=76) = 7.64$, $p = 0.054$). A second chi-square test compares groups C and V in trial four, indicating no significant differences after variable behavior appeared for the first time ($X^2(2, N=76) = 1.14$, $p = 0.565$). A third chi-square test compares group C and V in trial six, indicating no significant differences between the groups after variable behavior appeared for the second time ($X^2(3, N=76) = 3.58$, $p = 0.311$). Figure 4 shows the results of the trust subscale according to Körber et al. (2019). Taking into account individual differences, a type 3 mixed effects ANOVA with participant as random effect reveals a significant strong size effect of group on trust ($F(1, 74) = 16.29$, $p < 0.001$,

$\eta^2_{partial}$ = 0.180), and Greenhouse-Geisser-corrected significant medium size effect for trial on trust (F(5, 370) = 10.17, $p < 0.001$, $\eta^2_{partial}$ = 0.121). Additionally, there is a Greenhouse-Geisser corrected significant strong size interaction effect between group and trial (F(5, 370) = 19.83, $p < 0.001$, $\eta^2_{partial}$ = 0.211).

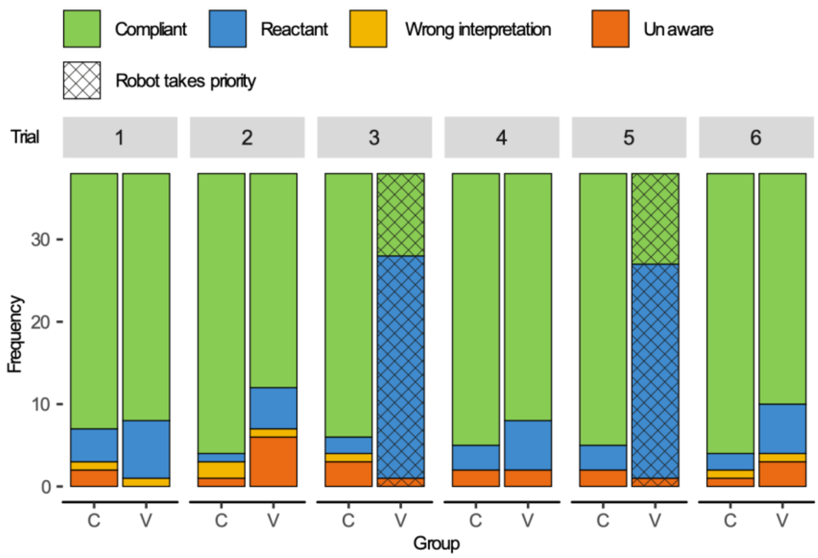

Figure 3. *Participants' reactions in the consistent (C) (N = 38) and the variable (V) group (N = 38). Checked bars mark trials where the robot took priority by showing dominant behavior.*

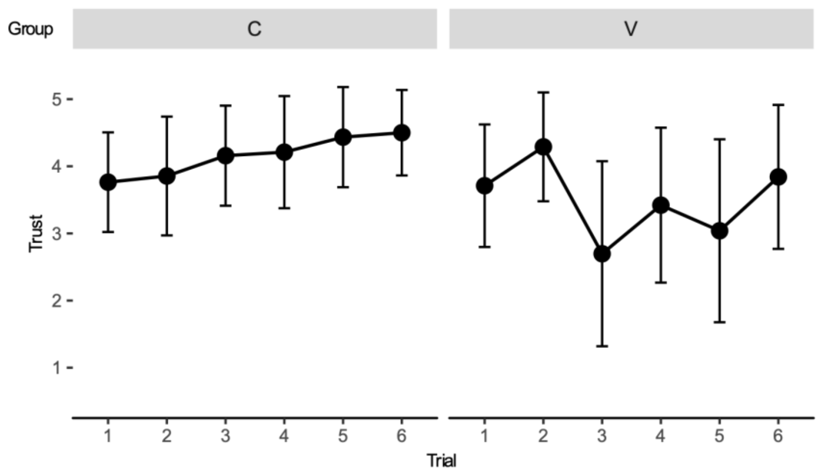

Figure 4. *The mean trust rating of the consistent (C) (N = 38) and variable (V) (N = 38) group is composed of arithmetic means of answers to the two items of the subscale trust of the TiA questionnaire (Körber et al. 2018). Ratings range from 1 = "strongly disagree" to 5 = "strongly agree". Error bars show standard deviations.*

4. Discussion

There are no significant differences in reactions between the C and the V group before and after the V group experienced the dominant robot behavior. Hence, $H_{1/1}$ is rejected. The variable robot behavior did not affect compliance in our study, neither after first nor second encounter with robot dominance. Human subjective trust on the other hand is significantly lowered in the V group compared to the C group, hence $H_{2/1}$

is supported by the data. Variable robot behavior shows an effect on subjective trust in our study. As introduced in chapter 1, social desirability bias or being observed by the experimenter may account for this acausal result.

The study succumbs some limitations. At first, small case numbers are achieved for the usage of bottleneck B. A bigger total sample size could allow more detailed analysis of this behavior. Multiple behavioral outcomes are rated as reactant behavior in the presented approach. Moving through B despite having correctly inferred the intention of yielding priority and moving through A despite the robot taking priority are both handled as reactant behavior. It was not taken into account whether the participant walked shortly before or after the robot in trials with dominant behavior. This criterion needs further consideration in following studies.

Additionally, for some participants, the back-off maneuver may have had a too long initiation phase. Video analysis suggests that this promoted classified reactant behavior that was actually a result of impatience to wait for the robot. Also shaking of the robot during acceleration and minorly deviating from the pre-defined stopping points may have played an influential role in the reactions of the participants.

In summary, the results indicate that variable robot behavior influenced subjective trust compared to consistent behavior while no differences in compliance were found. Hence, the proposed approach using compliance as a measure for behavioral outcomes in combination with subjective measures is promising to achieve valuable insights in further studies.

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