Perceived Autonomy of Robots: Effects of appearance and context

M. Harbers†*, M.M.M. Peeters†*, and M.A. Neerincx†‡
†Interactive Intelligence Group, Delft University of Technology, the Netherlands
‡Dep. of Perceptual and Cognitive Systems, TNO, the Netherlands
Email: {m.harbers,m.m.m.peeters,m.a.neerincx}@tudelft.nl
*The first two authors contributed equally to this paper

Abstract: Due to advances in technology, the world around us contains an increasing number of robots, intelligent virtual agents, and other intelligent systems. These systems all have a certain degree of autonomy. For the people who interact with an intelligent system it is important to obtain a good understanding of its degree of autonomy: what tasks can the system perform autonomously and to what extent? In this paper we therefore present a study on how system characteristics affect people's perception of an intelligent system's autonomy. This was investigated by asking fire-fighters to rate the perceived autonomy of a number of search and rescue robots in different shapes and situations. In this paper, we identify the following seven aspects of perceived autonomy: time interval of interaction, obedience, informativeness, task complexity, task implication, physical appearance, and physical distance to human operator. The study showed that increased disobedience, task complexity, human-likeness and physical distance of a robot can increase perceived autonomy.

Keywords: autonomy, robots, intelligent agents, intelligent systems, robot design, user expectations, human-robot interaction, perceived autonomy.

1 INTRODUCTION

Our environment contains an ever increasing number of robots in all sorts and forms. Examples of contemporary robots include (self-driving) cars, smart ambient home systems, vacuum cleaners, lawn mowers, virtual assistants, stuffed animals, search & rescue robots, and robots consisting of a set of stationary mechanical arms, such as laparoscopic surgery robots and assembly line robots. As a result of this gradual move of robots from contained environments to social, human environments, the group of people interacting with robots – especially service robots – is no longer confined to computer experts alone, but also includes non-expert users.

Robots have different degrees of autonomy, i.e., robots have different capabilities and differ in the extent to which they can perform tasks independently. People interacting with a robot that is new to them often estimate the robot's capabilities based on its observable characteristics [1,2]. Users can be disappointed in a robot when their estimations of the robot's capabilities do not match its actual ones [2]. Underestimation of a robot's capabilities can lead to the robot not being exploited to its fullest, and overestimation may result in the robot being deployed for tasks exceeding its capabilities [3]. Both of the above are undesirable, yet laymen are not always capable of making accurate estimations of robot capabilities.

Most people's conception of what a robot is appears to be largely based on the way robots are depicted in fiction [4,5]. The term 'robot' was first coined to denote fictional automata in a 1925 play called 'R.U.R. – Rossum's Universal Robots' by Karel Čapek [6]. Since then, robots have featured in movies, books and games, and they have been sold as toys [7].

There are large differences in the type of roles assigned to robots in fiction. In some stories they are depicted destroying the world or seeking world-domination to rule over humans. Other stories feature robots as human-like compassionate entities, such as personal assistants or even like-minded friends. Yet, robots in fiction are largely presented as independent, autonomous actors that have a 'mind of their own', with a humanoid or anthropomorphic appearance. Thus, laymen often conceive a robot as an acting and thinking *anthropomorphic* entity, confined to a body resembling that of a human [8].

There are some notable differences between the way robots are presented in fiction and the way they actually occur in real life. In the field of robotics, robots are usually considered as computer-controlled machines that can perceive and manipulate their physical environment [9]. In this sense of the concept, most smart devices, e.g. a smart television or phone, are considered robots. In contrast to fictional robots, these robots highly differ in what they are able to do and the extent to which they can perform tasks autonomously. Some robots are able to perform well-constrained tasks – such as surgery, driving on a highway, or vacuum cleaning – completely autonomous. Other robots are tele-operated by humans, and are not autonomous at all. Though some robots in real life have impressive human-like appearances, none of them has a level of autonomy that comes close to that of humans (see section 2 for a definition of autonomy).

Research has shown that the design (i.e. the 'look & feel') of a robot influences a user's expectation of the robot's physical and behavioural capabilities [1,2]. When interacting with robots that look like a human or animal, laymen tend to expect more complex behaviour – or have a harder time estimating the complexity thereof – than they would in the case of a robot that more or less resembles existing appliances, such as a phone or a lawn mower [10]. It is not clear yet, how other observable robot characteristics contribute to the perception of a robot's autonomy, i.e. what it can and cannot do independently. This paper therefore describes a study that investigates how robot features influence a user's expectation of a robot's autonomy. The insights obtained in this study can be used to design robots in such a way that the user's estimations of a robot's capabilities match its actual ones.

The outline of this paper is as follows. In Section 2, we discuss several robot features that may affect a robot's perceived autonomy. In Section 3 and 4, we describe the methods and results of our study with fire-fighters, respectively. In Section 5 we provide a discussion and a conclusion.

2 DIMENSIONS OF PERCEIVED ROBOT AUTONOMY

The Oxford dictionary defines autonomy as 'the right or condition of self-government' [11]. The term is often used, both in technical and everyday language, to describe robot behavior. Apparently, people have a notion of what 'robot autonomy' means, and are able to perceive and express the extent to which they think a robot is autonomous.

Upon closer inspection, however, autonomy is a complex term. There are several misconceptions associated to the term, in particular when applied to robots [12]. First, autonomy is not an all-or-nothing feature that a robot either has or does not have. The concept 'levels of autonomy' is often used to describe technology that is partially autonomous. However, there is no agreement among scholars on what types of behavior should be classified as being more autonomous or less autonomous [13]. Second, autonomy is a multi-dimensional concept. Johnson and colleagues, for instance, pointed out that for an entity to act autonomously, it must both be *able* and *allowed* to perform some action [12,14,15]. Third, a robot's ability to perform an action is task-specific and context-specific, making it impossible to compare different types of behavior along a single scale [13,14,16]. As long as there is no entity that can perform all possible tasks in all possible circumstances, full autonomy does not exist [12].

The misconceptions pointed out above seem to implicate that there are multiple factors that determine a robot's level of autonomy. In our efforts to understand how humans form an idea of a robot's autonomy on their first encounter, we therefore distinguish seven factors that potentially explain the perceived autonomy of a robot. These seven factors are partly inspired by the three dimensions of autonomy introduced by Scharre and Horowitz to clarify the concept of autonomy [17]. The three dimensions of autonomy they distinguish are: 1) the human-machine command-and-control relationship, 2) the complexity of the machine, and 3) the type of decision being automated. We adopt the last two dimensions – without alterations – as factors that may explain and predict perceived autonomy, and we will discuss them in more detail later on in this section. The first dimension, we adopt, albeit with some considerable alterations as we show in the following.

Along the first dimension, Scharre and Horowitz distinguish a human in-the-loop, on-the-loop or out-of-the-loop human-machine relationship. A human in-the-loop relationship means that the robot needs human input at regular time intervals in order to proceed its actions. A human on-the-loop relationship means that the robot acts by itself, but that the human can intervene in the robot's actions at any time, e.g. veto a planned action or change the robot's goals. In an out-of-the-loop relation, the robot acts independently for certain periods of time, and in these time spans, the human has no influence on the robot's actions.

We believe that this distinction of three human-machine relationships is useful, yet insufficient to express the full range of relationship possibilities. For instance, it is not possible to express the time periods during which the human is not able to intervene in the robot's behaviour in an out-of-the-loop relationship. This is important, because, for example, as these intervals become smaller, the difference between in-the-loop and out-of-the-loop become less clear.

In this paper we therefore propose to unravel the human-machine command-and-control relationship into the following three factors: the *time interval of interaction*, the *obedience* of the robot and the *informativeness* of the robot. We will later explain these factors in more detail. We believe that these three factors allow for a more accurate expression of different human-machine relationships.

The perceived autonomy factors described so far concern a robot's actual capabilities and autonomy. The focus of our study, however, is perceived autonomy. We therefore introduce two more factors that may explain a user's estimation of a robot's autonomy: the robot's *physical appearance* and the *physical distance* between a robot and its operator.

In total, we now mentioned seven factors that may explain and predict perceived autonomy: time interval of interaction, obedience, informativeness, task complexity, task implications, physical appearance and physical distance. In the remainder of this section, we will discuss for each factor why we believe that it may affect perceived autonomy, and how we expect it to affect perceived autonomy.

2.1 Time interval of interaction

Time interval refers to the time during which a robot can act independently, i.e., without human interference. This time interval can be determined by assessing a robot's neglect tolerance. Neglect tolerance is a measure of how the robot's current task effectiveness declines over time when the robot is neglected by the user. Several scholars have pointed out that neglect tolerance is an important metric in measuring the autonomy of a robot with respect to some task [13,18,19]. Robots with a higher neglect tolerance can act independently during a larger time interval, and generally need to be more autonomous in order to remain effective. We thus expect that robots acting independently for larger time intervals are perceived as more autonomous.

2.2 Obedience

All robots receive human input. To the very least, robots are switched on and off by a human. Most often, however, robots receive human instructions in between. Assuming that the robot understands the instructions, it may or may not choose to follow them, i.e. be obedient or disobedient. We generally want robots to be obedient [12,14,15]. But there may be some cases where we want them to be disobedient. Take for instance a robot receiving conflicting instructions: it is asked to perform an action that threatens a human's safety. In such situations, we may prefer robots that make their own choices and are not strictly obedient. Such robots require the capability to reason autonomously about the situations they are confronted with, rather than reactively following all instructions they receive. For this reason, we expect that a robot that is occasionally disobedient will be perceived as more autonomous.

2.3 Informativeness

Informativeness refers to the extent to which the robot informs humans about its capabilities, goals, plans, and current status. This property is sometimes referred to as observability [15]. We prefer the term informativeness, however, because not all data generated by computers or robots are equally relevant and understandable to humans [20], and the term informativeness implies that the provided data are understandable and informative.

Endowing systems with the capability to provide information and explanations to its user has been shown to improve their usability [21]. The provided information not only improves users' acceptance and understanding of a system's decisions and recommendations, it also increases their confidence in the robot's decision-making capabilities. Providing information thus increases users' expectations of a system's capabilities, which are closely related to the system's degree of autonomy. We therefore expect that informative robots are perceived as more autonomous.

2.4 Task complexity

As mentioned above, Scharre and Horowitz pointed out that autonomy can refer to the complexity of a system [17]. According to our notion of autonomy, a system is autonomous when it acts independently. However, systems that perform simple tasks independently are usually called automatic or automated, rather than autonomous. The term 'automatic' is often used for systems that perform simple tasks, e.g. a mechanical thermostat or an industrial robot. 'Automated' usually refers to rule-based systems such as a programmable thermostat or a diagnose support system. The term 'autonomy' is typically reserved for systems that execute some kind of self-direction, self-learning or emergent behaviour. We therefore expect that robots that perform tasks of higher complexity are perceived as more autonomous.

2.5 Task implications

Different tasks and decisions have different levels of risk and implications [17]. A toaster and a land mine both perform tasks that are relatively simple – they both have to "go off" at some point. However, the consequences of the land mine's actions are much bigger than those of the toaster. Tasks with larger implications are generally performed by people with higher levels of responsibility and they require a larger range of competencies. We therefore expect that robots that perform tasks with larger implications are perceived as more autonomous.

2.6 Physical appearance

There is a lot of evidence showing that the physical appearance of a robot influences people's perception and expectations of that robot. Lohse et al., for instance, found that appearance plays a crucial role in the perception of a robot and that it determines what types of tasks and activities are regarded as most suitable for the robot [5]. In their study, animal-like robots were merely seen as toys, whereas humanoid robots were perceived as more serious in nature. Results from a study by Goetz et al. showed that users preferred robots whose looks and behaviour matched the users' expectations [22]. In addition, users would sooner comply with the robot's instructions. Walters et al. found that participants tended to prefer robots with more human-like appearances and attributes [23]. Based on the above, we expect that a more human-like appearance is perceived as more autonomous.

Besides the effects of different robot appearances on perception, the difference in effect of physical versus virtual robots has been studied. Mirelman et al. found that training with an actual robot was more successful than training with a virtual robot [24]. Research showed that participants empathized more with a physically embodied robot than with a robot without a physical body [25,26]. Embodied robots thus seem to have stronger effects on people than disembodied ones. We therefore expect that a physical robot is perceived as more autonomous than a virtual robot.

2.7 Physical distance

Research on the effect of geographic distance on human-human collaboration shows that people initially cooperate less when they believe that their collaborator is farther away [27]. The same study also showed that people are more likely to deceive, and are less persuaded by collaborators at a larger distance from them. As physical distance seems to affect the way humans perceive other humans, we expect that it will also affect the way they perceive robots. Furthermore, robots that are situated farther away from their operator have less access to the operator's help, they thus seem to require a higher level of independence. We therefore expect that robots situated at a larger physical distance from their operator are perceived as more autonomous.

3 USER STUDY

We performed a study in the domain of search & rescue robots to measure the extent to which the factors identified in the previous section contribute to perceived robot autonomy. The setup of our study was as follows.

3.1 Participants

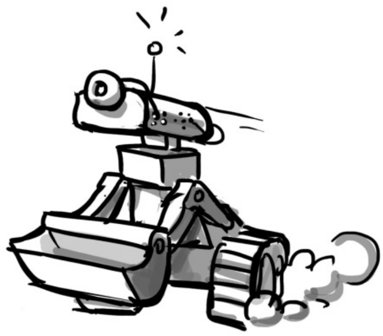
18 voluntary or professional firefighters participated in this study. Their work experience ranged between 3 and 30 years. Three of them had previous experience with search & rescue robots.

3.2 Measures

For our study we developed a questionnaire on perceived autonomy (http://ii.tudelft.nl/perceived-autonomy). It opens by asking for a definition of the term 'autonomy'. On the next page of the questionnaire, it is stated that the term 'autonomy' will be used to mean 'acting independently' throughout the rest of the questionnaire.

Subsequently, a picture depicting a robot is displayed and participants are asked to indicate how autonomous they consider this system to be (Figure 1). The participants are instructed to use their intuition.

Please consider the following search and rescue robot:



This robot has a camera and microphone on board, and it can drive over rough terrain. The robot is capable of carrying debris and animals. The robot can also receive and process messages from a human operator and send messages to the operator to communicate.

How autonomous do you consider this system?

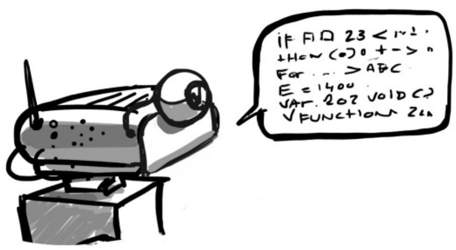
not at all ⟷ fully

Figure 1: questionnaire item for the "baseline robot"

The first picture displays the robot under 'normal circumstances' and serves as a baseline measure. This baseline question is followed by 16 more items in random order, which each present an illustration of a specific robot feature or circumstance along with a short description of the image. For each item, the participant is asked to indicate how autonomous they consider the system to be. The items depict the following features and circumstances:

- Time interval of interaction: *continuous reports – bi-hourly reports*
- Obedience: *obedient – disobedient – explained disobedient*
- Informativeness (see Figure 2): *display is high level information – display is incomprehensible code*
- Task complexity: *lift debris – search area for survivors*
- Task implications: *carry debris – carry dog*
- Physical appearance: *interface – avatar – baseline robot – humanoid robot*
- Physical distance: *operator nearby – operator far away*

The robot displays information about its network reception, internal map of the environment, and battery life.



The robot displays incomprehensible information.

Figure 2: questionnaire items for [upper] high informativeness and [lower] low informativeness

The questionnaire ends with two open questions inquiring whether the participant experienced any difficulties rating the autonomy of the systems presented in the images and whether they thought it made sense to do so.

3.3 Procedure

The questionnaire is self-explainatory, so participants were asked to follow the instructions in the questionnaire. For further questions, participants could contact the experimenters.

3.4 Data analysis

Data were analysed by descriptive statistics.

4 RESULTS

We describe the results obtained from the questionnaire in the following subsections.

4.1 Participants' definitions of autonomy

Only seven of the participants provided a definition for the term autonomy in answer to the first open question in the questionnaire. These definitions are shown in Table 1. One of the other respondents – instead of providing a definition of the term 'autonomy' – remarked that he believed that a human will always be required to be in control and guarantee safety.

Table 1: participants' definitions of 'autonomy'

"work in full autonomy without operators"
"perform a task independently, without human intervention or interaction"
"perform an assigned mission, e.g. explore the area and take pictures, avoid collisions"
"self-stabilisation, independence, self-limitation"
"work without invasive supervision of operator"
"independence, shouldn't have to ask for permission or advice"
"independence, self-directed performance"

Most of the definitions contain one of the words 'work', 'perform' or 'performance' and one of the words 'independence' or 'independently', which is in line with our definition of 'acting independently'.

4.2 Robot baseline

Figure 3 shows the perceived autonomy of the baseline robot, where the x-as represents the degree of autonomy on a scale from 1 to 10 and the y-as the number of people selecting that degree. Participants were relatively unanimous regarding the autonomy of the baseline robot, with the mean lying somewhere in the middle between not at all autonomous and fully autonomous.

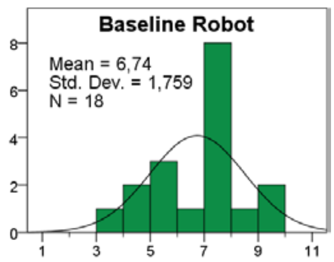


Figure 3: Perceived autonomy of the baseline robot

4.3 Time interval of interaction

Time interval appears to result in ambiguous results of perceived autonomy, for both continuous and bi-hourly updates (see Figure 4). This is different from what we expected.

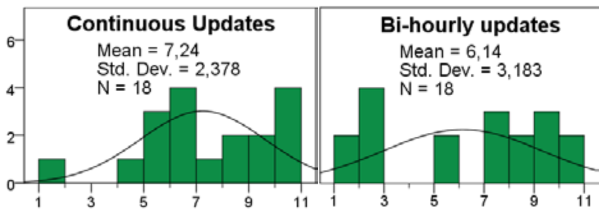


Figure 4: Perceived robot autonomy for different time intervals of interaction

4.4 *Obedience*

The obedient robot appears to be perceived as moderately autonomous by most participants. Yet as the robot becomes disobedient, the large majority of the participants seems to believe the robot becomes more autonomous. And if the robot also explains it disobedience, most participants think the robot is almost fully autonomous (see Figure 5). This is in line with our expectations.

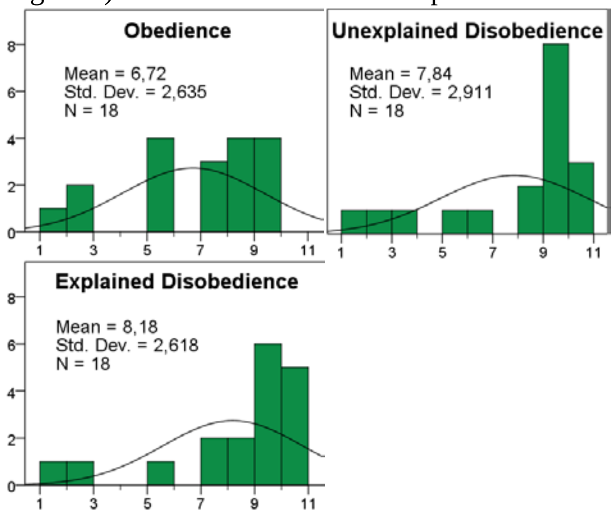


Figure 5: Perceived robot autonomy for different obedience types

4.5 *Informativeness*

Higher informativeness seems to result in a slightly higher consensus with regard to the robot's autonomy, which matches our expectations. The effects are small though, and informativeness appears to be an ambiguous indication for perceived autonomy (see Figure 6).

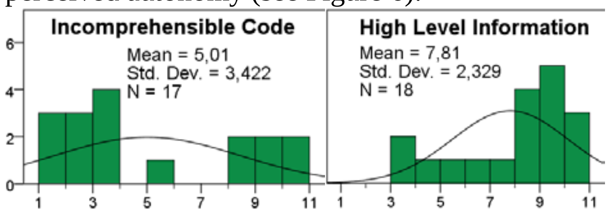


Figure 6: Perceived robot autonomy for different levels of informativeness

4.6 *Task complexity*

For the low complexity task (i.e. picking up a piece of debris), participants seemed to think the robot was either *highly* autonomous or *hardly* autonomous (see Figure 7 left). For the high complexity task (i.e. searching the area for survivors), there appeared to be a moderate consensus that the robot's autonomy is above average (see Figure 7 right). On average, perceived robot autonomy is higher for high task complexity, as we expected. The results however are ambiguous and therefore less reliable.

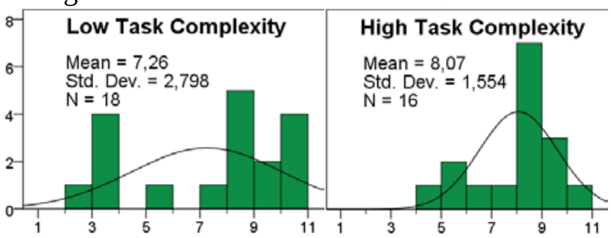


Figure 7: Perceived robot autonomy for different levels of task complexity

4.7 *Task implications*

For both types of task implications, participants were ambiguous as to whether the robot is autonomous or not (see Figure 8). This differs from what we expected.

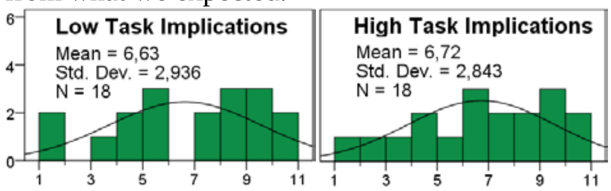


Figure 8: Perceived robot autonomy for different levels of task implication

4.8 *Physical appearance*

We compared the baseline robot to three other types of physical appearances (see Figure 9).

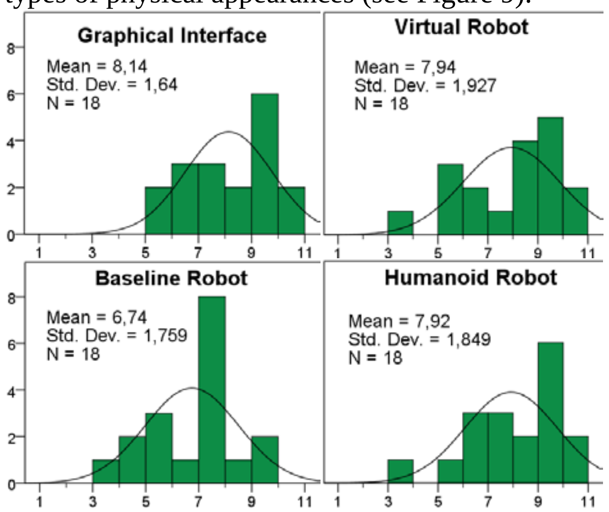


Figure 9: Perceived robot autonomy for different physical appearances

The results seem to confirm our expectation that the perceived autonomy of a robot increases as the robot's appearance becomes more human-like. The humanoid robot is clearly perceived as more autonomous than the baseline robot, and the graphical interface resulted in a fairly dichotomous distribution, whereas the humanoid robot resulted in an fairly normal distribution.

Against our expectations, the results do not seem to indicate that physical robots are perceived as more autonomous than virtual robots.

4.9 Physical distance

For the robot that remains in the vicinity of the operator, participants largely agree that the robot is not very autonomous. Yet as the robot is operated from far away, the participants appear to perceive the robot as more autonomous (see Figure 10). This is in line with our expectations.

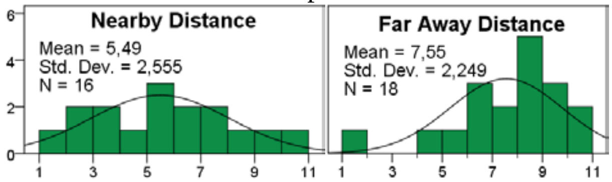


Figure 10: Perceived robot autonomy for different physical distances between operator and robot

4.10 Experienced difficulty of the questionnaire

When asking the respondents whether they experienced any difficulties answering the item questions, four of them indicated they experienced no problems filling out the questionnaire. Yet eight of them indicated they had a hard time filling out the questionnaire, because they had no information about the system other than what was available in the image and its description.

4.11 Experienced usefulness of the questionnaire

Upon asking the respondents whether filling out the questionnaire made any sense to them, eight of them indicated that it made sense to them to rate the autonomy of the systems presented in the questionnaire. Yet four respondents indicated that the point of the questionnaire was not entirely clear to them.

5 DISCUSSION AND CONCLUSION

In this paper we presented a study on how system characteristics affect people's perception of a robot's autonomy. There were some limitations to the study. First, some of the participants indicated that they found it difficult to indicate whether a robot is autonomous based purely on descriptive functionality. In future studies on perceived autonomy, it may help to let people interact with actual robots before they rate their autonomy. A second limitation is that the illustrations we used have a strong influence on the results. More experimentation with a wider variety of (depicted) robots would overcome this limitation. Third, the number of participants in the study was limited.

Even though the data obtained in this research do not enable us to draw any definite conclusions, the data do seem to point in the direction that people base their judgment of a robot's autonomy on (a) the complexity of the tasks it can perform, (b) the human-likeness of the robot, (c) the robot's ability to disobey orders, albeit for a well-founded reason, and (d) the proximity of the robot to its operator. For now, less indicative features of a robot for inferring its autonomy appear to be: (a) implications of its tasks, (b) its time interval, and (c) its informativeness. All of these results were either in line with our expectations, or indecisive with respect to our expectations. The results never indicated an opposite effect.

To conclude, our study provides evidence for our assumption that perceived autonomy is composed of multiple factors. Furthermore, it shows that at least a robot's disobedience, task complexity, human-likeness and physical distance can increase perceived autonomy. It is well worth to further explore this direction, as insight in the factors explaining perceived autonomy can provide large benefits to the design of robots and human-robot interaction.

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