Can I Just Pass by? Testing Design Principles for Industrial Transport Robots

Marijke Bergman, Sandra Bedaf, Goscha van Heel and Janienke Sturm
School of HRM and Psychology, Fontys University of Applied Sciences, Eindhoven, The Netherlands

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Abstract: Currently, two types of industrial collaborative robots are emerging: collaborative robot arms and transport robots. For such robots to cooperate with humans, intuitive interaction is required. They have to display behaviour that is predictable and legible and elicits positive emotions. In this paper we examine the application of two general design principles to the design of transport robots: (1) use analogies from nature, and (2) adhere to social rules. Both are expected to result in better user-experience and understanding of the behaviour and intentions of a transport robot. The current study tests the effects of using 1a) a curved path and 1b) average walking speed in combination with deceleration upon nearing the human, and 2a) swerving to the right and 2b) respecting personal space. The principles tested in this study show positive effects for user experience and legibility. However, predictability is not improved. Options for additional adjustments, such as the use of communicative lights, are discussed.

1 INTRODUCTION

In industry robots and humans cooperate increasingly closely. So called collaborative robots are no longer working in isolation, separated from their users by fences or safety screens. The environment in which collaborative robot operate will be less structured and it is to be expected that more and more users will be less experienced than traditional operators and will have had less formal training to work with these robots (Freese et al., 2018). In particular mobile transport robots may encounter humans who are casually passing by. Consequently, when collaborative robots are implemented the human-robot interaction changes as well. Collaborative robots and humans form a team, as it were. In human teams there is ample and timely exchange of information (McNeese et al., 2018). Not all information is exchanged verbally, there is a fair amount of non-verbal communication as well. Such sharing of information is necessary in human-robot teams as well.

Cooperation and collaboration between robots and humans require natural and intuitive interaction. (Korondi et al., 2015). The fluency of the interaction can be improved if humans can predict or anticipate the actions of the robot (Hoffman & Breazeal, 2007; 2010). Predictable robot motion, motion that is expected, supposedly helps humans to trust and understand the robot (Dragan et al., 2013). Furthermore, to obtain a fluent and intuitive interaction, *legible* and intent-expressive behaviour is required, helping humans to understand the robot's intentions, (Dragan et al., 2013; Lichtenthäler & Kirsch, 2016).

Two types of robots are becoming common co-workers in factories: 1) collaborative robotic arms used for pick-and-place tasks or that may help humans by handing over objects or mounting parts, and 2) transport robots and autonomous guided vehicles (AGV) that fetch and deliver parts and products. Both types may encounter challenges where intuitive, natural interaction and legible behaviour are concerned. Interaction that is intuitive and natural will not only improve user experience but will also reduce cognitive load for the user.

The concept of cognitive load is used in interaction design and the field of UX (user experience) as the amount of mental resources needed to use a product or its interface. Cognitive psychology and engineering psychology use similar concepts such as information load, task load and workload. The amount of information humans can process is limited by, amongst others, the capacity of working memory, the complexity of the information, and the amount

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and diversity of attention the interaction and other events in the environment demand (see, e.g., Wickens et al., 2015). In cases where more information has to be processed than the available processing capacity accommodates, humans will miss information, get stressed and experience cognitive failures (Broadbent et al., 1982; Simpson et al., 2005; Wadsworth et al., 2003). Moreover, limiting cognitive load in human-robot interaction is interrelated with increasing trust in the robot (Ahmad et al., 2019; Novitsky et al., 2018) and acceptance (Palinko & Sciutti, 2014).

In line with this, research shows that the more predictable the motions of a robot are, the better human task performance (Koppenborg et al., 2017) and the higher experienced comfort or safety will be (Butler & Aga, 2001; Tan et al., 2009). The use of well thought out design principles could thus be beneficial for interaction and teamwork (Petruck et al., 2016). Many principles may be discerned, however, for this study we will limit ourselves to two general principles that are applicable in many contexts and for most types of robots.

One principle is to **make use of metaphors and analogies from the natural world** i.e. from nature. We interpret the looks and actions of objects and creatures we do not know within a frame of reference based on things and situations that are familiar to us. We create mental models using analogies and metaphors of similar objects and situations from the, mostly natural, world around us. Employing natural cues utilizes existing, well-calibrated mental models and improves the quality and efficiency of the interaction (Goodrich & Olsen, 2003). Furthermore, we are subject to animism and tend to project characteristics of lifeforms onto non-living objects (Korondi et al., 2015). In designing the behaviour of, mostly social, robots this is used by modelling it after human behaviour and interactions between humans (Kittmann et al., 2015; Takayama et al., 2011). Such modelling is claimed to help interpret, understand and predict the motion behaviour of robots (Goodrich & Olsen, 2003; Lichtenthäler & Kirsch, 2016). For instance: “The industrial robot is *like an extra arm* to work on the product”.

Using lifelike appearances or behaviour does not necessarily mean that a robot should specifically look and behave as a human (de Graaf et al., 2015). In agreement with Kruse et al. (2013), we define *naturalness* as the similarity of (low level) behaviour between robots and living creatures. Bergman et al. (2019) suggest that, in addition to or instead of modelling after humans, emulating animalistic behaviour and using animal metaphors can be used to make the interaction with collaborative robots more intuitive and to support building useful mental models. For instance: “The transport robot is *like a dog* fetching things”. Similar claims are made by others (Koay et al., 2013; Philips et al., 2012; Sharp et al., 2019). Humans often have an intuitive understanding of what an animal is communicating and how to interpret their signalling behaviour. Thus, mimicking or emulating relevant aspects of such behaviour may serve well to improve the *legibility* of robot behaviour (Lichtenthäler & Kirsch, 2016). However, care should be taken to assure that such analogies and metaphors are suitable in the context in which they are used. Also, the looks and behaviour should be consistent with the actual capabilities of the robot (Rose et al., 2010), thus providing relevant cues and interaction affordances (Hoffman & Ju, 2014).

Another principle is to **adhere to social rules**. This principle partly overlaps with using analogies from the natural world. Behaviour displayed by humans as well as some animals conform to social rules. Various studies in human-robot interaction show that similar social rules displayed by the robot, result in positive user experience and more intuitive interaction. Consequently, the robot is seen as sociable, where *sociability* can be defined as adhering to (high-level) cultural conventions (Kruse et al., 2013).

Social skills are considered vital for robots that function as companions or assistants (Ogden & Dautenhahn, 2000), but smoothen interaction with other types of robots as well. Among such skills are not interrupting humans unnecessarily, moving out of the way and slowing down when getting close, avoiding to approach a human from behind, and showing awareness or attention (Dautenhahn, 2007). For instance, respecting someone’s personal space makes a user feel safer and more comfortable around a robot (Bortot et al., 2012; Rios-Martinez et al., 2015; Tan et al., 2009). Being polite through approaching and turning toward a user helps to initiate interaction (Kato et al., 2015). Acknowledging a user by a social gesture like nodding, increases the social acceptance of an industrial, non-humanoid, robot (Elprama et al., 2016).

In this study we focus on applying these two interrelated design principles, as to how they help users to understand the behaviour of and interact intuitively with transport robots. Expectations are, that using design principles that a) use analogies from nature and b) adhere to social rules, will result in a more positive experience and in a better understanding of the behaviour and intentions of a transport robot. That is, the application of such principles will result in positive emotions or affect as opposed to negative emotions or affect, and it will result in higher legibility and predictability of the behaviour. We aim at a parsimonious approach, looking for maximal effects of minimal adjustments in existing collaborative transport robots. The movements and behaviour in robots currently available, are limited mainly by technical constraints and safety guidelines. Redesigning the behaviour of such robots is considered challenging (Dautenhahn, 2007; Liu et al., 2019). In addition to being parsimonious, adjustments should contribute to reducing the cognitive load put on the user.

2 DESIGN PRINCIPLES FOR TRANSPORT ROBOTS

Assuming that such general principles as mentioned above may improve user experience, it is useful to determine how these principles can be made more specific for transport robots in an industrial work environment. Here AGVs and transport robots are no longer confined to warehouses where they work in isolation. Autonomous transport robots now emerge in settings where they, for instance, bring and fetch parts for assembly workers. They thus move around in factory halls together with humans. So, the question arises what natural behaviour would be suitable to use. Which social rules are important for an industrial transport robot?

2.1 Analogies from Nature

Implementing natural motion in a transport robot aims at increasing its acceptability through making it behave more like a human or an animal. To emulate natural behaviour and to make a transport robot more lifelike some animation techniques may be useful. For instance, in nature living creatures usually follow *arched* trajectories, in contrast to mechanical objects that more often follow straight paths. Thus, making a transport robot move through a curved path can be used to make it more predictable (Kruse et al., 2013; Olivera & Simmons, 2002) or to deduce its intentions more easily (Mavrogiannis & Knepper, 2019).

A second animation technique *slow in and slow out* can suggest the natural acceleration and deceleration of living creatures. Also, it is known that creatures or objects approaching at high speed, elicit fear and often result in flight reactions (Stankowich & Blumstein, 2005). In line with this, Kirby et al. (2009) suggest limiting the *velocity* of transport robots to human walking speed between 1 and 2 m/s, as to increase perceived safety. Butler and Aga (2001), and Pacchierotti et al. (2005) also showed that the relative speed of a mobile robot is an important factor in user experience. Additionally, Kruse et al. (2013) showed that reducing velocity when approaching a person improves user experience with mobile robots. Existing mobile robots mostly conform to walking speed because of safety regulations.

In addition, it may be helpful to make internal robot states, like being stand by or in error mode, visible in an intuitive manner. This may be achieved by mimicking being at rest or sleeping, or being confused, and draws on a familiar frame of reference. Animated lights (Baraka et al., 2016) or a pulsing light mapped to the rhythm of a human heartbeat (Wessolek in Harrison et al., 2012), for example, may be used to communicate state or intentions. In this case light is used to

It is suggested regularly, that adding a face or a snout to a robot will help to generate a focal point for interaction, referring to objects or locations and helping to infer the intentions of a robot. However, adding a head or snout and gazing behaviour to a transport robot would require quite extensive adjustments and hardly be parsimonious (Admoni & Scassellati, 2017). Also gazing behaviour may increase the cognitive load if it distracts the user from the task at hand.

In the current research a) a curved path or *arc*, and b) average walking speed in combination with *slow in and slow out* will be used deliberately to make the communicative behaviour of the robot more intuitive and to improve human-robot interaction. Some existing AGVs and transport robots use of a curved path to avoid obstacles or average walking speed in combination with slow in and slow out for safety reasons. However, these movements are often unintentional, i.e. not the result of consistent implemented natural motions derived from analogies from nature.

2.2 Social Rules

According to Kruse et al. (2013) applying social rules deals with modelling and respecting cultural norms. This helps to prevent discomfort and to improve the interactions. Typical rules in the context of mobile robots are that the robot should keep an adequate distance as to respect personal space, should move to its right when it approaches from the front or should slow down when encountering humans. Currently, many transport robots approach humans as obstacles, moving in a straight line towards the obstacle before stopping or going around it at a short distance.

In general, humans prefer to stay out of each other's personal or intimate space, when close contact is not essential. Several studies show, that humans feel more comfortable with mobile robots that respect personal space by remaining at a *distance* of 1.22m up to 2.44m (Khambhaita & Alami, 2020; Kirby, 2010; Kruse, et al., 2013; Rios-Martinez et al., 2015; Torta et al., 2013; Walters et al., 2009). Shorter distances may sometimes be acceptable though. This may depend on the specific context and spatial layout or cultural and personal differences (Kirby, 2010), and by the size of the robot (Butler & Agah, 2001). Yet overall, humans prefer a robot to stay out of their personal and intimate space when they pass each other (Pacchierotti et al., 2006).

Moving to one's right when someone is walking towards another person is a common social rule in many countries. When a mobile social robot is approaching a person in a hallway it is also preferred that the robot *moves to its right side* of the hallway (Kirby et al., 2009; Pacchierotti et al., 2005; Rios-Martinez, 2015). In contrast, Neggers et al., (2018) claim that there is no difference between left or right passage. Some studies indicate that the onset of this evasive movement should start in time (Fernandez et al., 2018; Pacchierotti et al., 2006) or at a distance of 6 meters (Pacchierotti et al., 2005). The optimal lateral distance between human and robot is inconclusive. Some studies state that the robot should move as far to its right as the layout of the hallway allows (Pacchierotti et al., 2005). However, this lateral distance may also be influenced by many different factors such as the form, size and speed of the robot (Rios-Martinez, 2015).

It is to be expected, that the aforementioned social rules will apply to social robots and transport robots or AGVs alike. The current study will include a) swerving to the robot's right, and b) respecting personal space by keeping an adequate distance from humans.

2.3 Current Study

The current study explores a) the effect of the movements of a transport robot on the experienced emotions or affect by humans, and b) the effect of the movements of the robot on its legibility and predictability. We examine how using the design principles, as explained above, influence the user experience, as well as the legibility and predictability of the movement behaviour of the robot. We follow the definitions given by Dragan et al. (2013) and Lichtenthäler and Kirsch (2016), where *legible behaviour* is behaviour that ensures the intentions of the robot can be understood, and *predictable motion* is motion that is expected and can be foretold, helping humans to understand the robot's intentions (Dragan et al., 2013). It is to be expected, that the application of the principles used here, will result in positive emotions or affect, as opposed to negative emotions or affect, and it will result in higher legibility and predictability of the behaviour.

The user tests consist of two experimental conditions where a mock-up transport robot, inspired by the MiR100, is used. The transport robot approaches a human from the front before passing, in a constrained area like a factory hall: 1) the robot moves along a straight path and, using the animation technique *slow in and slow out*, stops in front of the participant, and 2) the robot uses a curved path, based on the animation technique *arched trajectories*, to move around the participant using social rules such as swerving to its right and respecting personal space. Both conditions will use an average walking speed. All dependant variables, *affect, legibility* and *predictability*, will be measured by asking participants to rate their experiences on a 5-point rating scale.

3 METHOD

3.1 Participants

The individual user tests with two conditions were conducted at Fontys University of Applied Sciences in Eindhoven, the Netherlands. A total of 30 adults (13 male and 17 female) participated in the test. Among the participants were participants from the general public, as well as students and lecturers of the Fontys school of HRM and Psychology. Most participants had little or no experience with transport robots or AGVs. All participants were aged 18+. Further background information was not registered for privacy reasons. Participants were selected based on their availability at the test location and randomly assigned to one of the two conditions. This resulted in 8 male and 7 female participants for condition 1, and 5 male and 10 female participants for condition 2.

3.2 Measures

The questionnaire consisted of a total of 15 items that were rated on a 5–point answering scale (1 = totally disagree, through 5 = totally agree) as a subjective measure of the user experience. The first part of this questionnaire was loosely based on the item scales *perceived safety* and *likeability* from the Godspeed questionnaire (Bartneck et al., 2009), translated from English into Dutch. These items were used to measure positive and negative affect. A statement "*I felt* ..." was used, followed by one of 13 adjectives, for example *safe*, *agitated*, *relaxed*, *anxious*, *pleasant* or *unpleasant*. All adjectives were placed in random order. Additionally, two statements to assess the legibility and predictability of the robot behaviour were included (Lichtenthäler & Kirsch, 2016).

Furthermore, a short semi-structured interview was conducted afterwards to gather additional information on how participants experienced the specific movements of the transport robot, as well as its speed. These interviews will help to understand how and why the design principles may work for the participants.

3.3 Procedure

The user tests were conducted in a public space at the university. A radio-controlled car was given a casing inspired by the looks of the MiR100 (Mobile Industrial Robots A/S; see Figure 1). The MiR100 is an autonomous transport robot that measures 890 mm x 580 mm x 352 mm. Its maximum speed is 1.5 m/s, which is comparable to an average walking speed. A Wizard of Oz method was applied in this study, as the test leader operated the mock-robot without the participants knowing. All user tests were filmed with permission of the participants. After a short introduction and signing of the informed consent, participants were assigned to one of the two conditions.

In condition 1 the robot started to move once the participants passed *line a*, at an average walking speed of approximately 1.1 m/s to 1.4 m/s, following a straight path from Point B towards point A (see Figure 2). The robot started to slow down after passing *line e* and when the participant reached *line c* the robot stopped at *line d*.

In condition 2 the robot also started to move at average walking speed in a straight path from Point B towards point A once the participants passed *line a* (see Figure 3). After passing *line f* the robot moved to the right using a curved path. The distance between the participants and the robot, between *line c* and *line d,* was approximately 30 cm. After passing *line c* the robot returned to its original path, again through a curved path, and continued to move towards point B in a straight path.

Figure 1: Scaled radio-controlled car with the casing inspired by the looks of a MiR100.

For both conditions, points A and B were the same and marked on the floor using tape, just as *line a* through *f* (see Figure 2 and Figure 3). Participants were instructed to stand on point A and to start walking, at normal speed, towards Point B once the researcher would say "go".

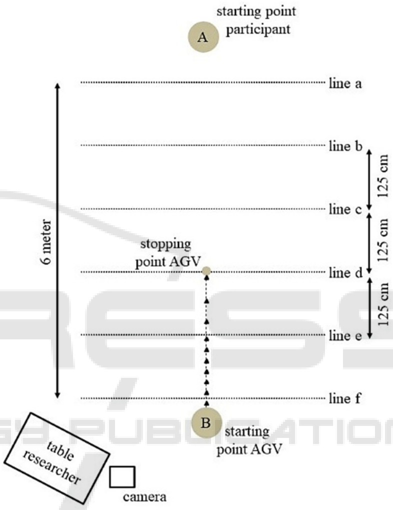

Figure 2: Straight path of the robot in condition 1.

Participants were informed that when they would start to walk, the robot would start to move towards them. However, no information was given on how the robot would move. This situation was closely observed to see if and when the participant would walk around the robot to reach point B. After performing the test, participants were asked to fill out the questionnaire and to participate in the interview. All interviews were audio recorded.

For the quantitative data from the questionnaire, statistical tests were performed to determine differences between the two conditions and to examine to what extent the scores for affect deviate from the middle value of the rating scale. The qualitative data from the interviews were transcribed and coded following the grounded theory method of open, axial, and selective coding.

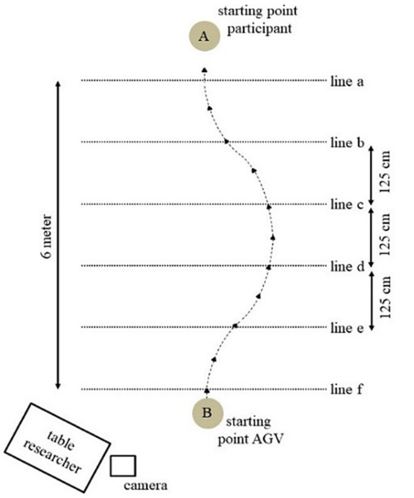

Figure 3: Curved path of the robot in condition 2.

4 RESULTS

4.1 User Experience and Affect

To determine the effect of the movements of the robot on the experienced emotions or *affect*, the scores on the items measuring affect were tested against the scale middle value, i.e. 3 on a 5-point scale (One Sample *t* Test). Twelve of the 13 items measuring affect were used in the analyses. One item, *surprising*, was excluded, since it was deemed ambiguous.

For condition 1, *straight path*, the mean scores for items indicating negative affect are, in general, significantly lower than the scale middle value (see Table 1). Of the scores for items indicating positive affect, only the items *calm* (*t*(28) = 2.358, p = .033, M = 3.6, SD = .99) and *relaxed* (*t*(28) = -3.761, p = .002, M = 3.9, SD = .96) are a significantly higher than the middle value. These results indicate that, in general, the straight path of the robot is not experienced distinctly negative by the participants. Moreover, the scores are rather neutral for this condition.

Table 1: Mean scores for negative affect in condition 1 tested against the middle value of the 5-point rating scale.

Affect	Mean	SD	t-value df = 28
intimidated	2.3	1.23	-2.092*
suspicious	3.0	1.36	0
uneasy	2.2	1.27	-2.449**
tensed	2.2	1.15	-2.703**
unpleasant	2.0	1.00	-3.873**
scared	1.6	0.74	-7.359**
overall	2.22		

* p-value ≤ .10; ** p-value ≤ .05

For condition 2, *curved path*, the scores for negative affect are, similar to condition 1, lower than the middle value of the 5-point answering scale (see Table 2), implying that the robot using a curved path is not experienced as negative either. Though the scores for negative affect in condition 2 seem to be even lower than in condition 1, the difference between the two conditions is not significant (using an Independent Samples *t* Test). However, when comparing individual items, it became apparent that the curved path used in condition 2 was experienced as less intimidating by the participants (M = 1.6, SD = .91), than the straight path of the robot in condition 1 (M = 2.3, SD = 1.23), *t*(28) = 1.852, p = .075.

Table 2: Mean scores for negative affect in condition 2 tested against the middle value of the 5-point rating scale.

Affect	Mean	SD	t-value df = 28
intimidated	1.6	0.91	-5.957**
suspicious	2.9	1.25	-0.414
uneasy	2.2	1.08	-2.863**
tensed	2.1	1.10	-3.287**
unpleasant	1.9	0.96	-4.298**
scared	1.6	1.11	-4.641**
overall	2.06		

** p-value ≤ .05

The scores for positive affect in condition 2 were, in general, above the middle value of the 5-point answering scale, though not all significantly so (see Table 3). This implies that the robot using a curved path is experienced as fairly positive. Overall, the scores for positive affect do not show significant differences between conditions 1 (M = 3.4, SD = 0.18) and condition 2 (M = 3.6, SD = 1.09), using an Independent Samples *t* Test. It seems that neither a curved, nor a straight path do elicit strong emotions

Table 3: Mean scores for positive affect in condition 2 tested against the middle value of the 5-point rating scale.

Affect	Mean	SD	t-value df = 28
safe	3.8	1.42	2.175**
comfortable	3.4	1.24	1.247
at ease	3.5	1.19	1.522
tranquil	3.8	1.08	2.863**
relaxed	3.3	1.05	1.234
calm	3.9	1.19	2.827**
overall	3.6		

** p-value ≤ .05

4.2 Legibility and Predictability

To determine the effect of the movement of the robot on its legibility and predictability, the scores on these items were compared for the two conditions, again using an Independent Samples *t* Test. The scores for these items indicate that participants rated the curved path of the robot in condition 2 (M = 4.1, SD = 1.35) as significantly more *legible* than the straight path used in condition 1 (M = 3.1, SD = 0.99), $t(28) = -2{,}783$, $p = 0{,}011$). The scores regarding the predictability of the robot of condition 1 (M = 2.4, SD = 0.9) and condition 2 (M = 2.7, SD = 1.34) showed no significant difference. Also, both conditions score below the middle value of 3 on the 5-point answering scale, suggesting both the straight and the curved path were not seen as very predictable.

In addition to the quantitative analyses, the results from the semi-structured interviews clearly show overlap with the results from the questionnaires. For both conditions, participants stated they failed to predict the robot's next move. They explained that they, unsuccessfully, searched for contact with the robot, hoping to be able to predict its next move. Several participants compared this need for contact to the situation where two people, who walk in the opposite direction towards each other, can communicate their path and their next move using non-verbal behaviour, such as eye contact in combination with body language. In order to improve the legibility, participants suggested to add turn signals and brake lights to the robot, or to project its path on the floor.

4.3 Qualitative Data

Where the design principles are concerned, the qualitative analyses give some interesting additional insights. First, the use of **analogies from nature** through moving along an *arched trajectory*, results in less negative experiences shared by the participants, than the statements made by the participants who experienced the straight path condition. Participants of condition 2 mentioned that using the curved path resulted in the robot displaying more natural movement or behaviour. Such an experience was not mentioned by the participants of condition 1.

The participants of condition 1 appreciated the deceleration of the robot, which was based on the animation technique *slow in slow out*, as it gave them the time to anticipate the actions of the robot. However, the majority of them did not understand why the robot slowed down and stopped in front of them. Multiple participants also wished that the robot would have moved to the side instead of moving straight towards them.

The majority of the participants thought the *velocity* limited at natural walking speed of the robot was appropriate. Some participants, however, preferred the robot to move slower.

As for adhering to **social rules**, in condition 1 the vast majority of the participants thought the stopping *(social) distance* of 125 cm was fine. In condition 2 the robot passed the participant at a distance of 30 cm. None of the participants of condition 2 experienced this as an anxious or threatening situation.

5 DISCUSSION

Overall, the use of the two design principles tested here, show positive effects for the user experience Analogies from nature, operationalized through the *curved path* and the *deceleration* of the robot, show positive effects on the user experience, in particular where affective experiences are concerned. This coincides with adhering to social rules such as *swerving to the right*. Also, these design principles appear to improve the legibility of the transport robot. However, as far as predictability is concerned, these principles do not seem to contribute much. This result is in contrast with previous research (Kruse et al., 2013; Olivera & Simmons, 2002). Yet, other earlier studies indicate that path adaptation may be more confusing and more uncomfortable than velocity adaptation (Kruse, 2014). Furthermore, the concepts legibility and predictability may be confounded (Lichtenthäler & Kirsch, 2016). In the current experiment, the participants in condition 1 experience the adaptation in velocity as positive, as it gives them time to anticipate the behaviour of the robot. This is in line with the findings of Kruse.

Though the design principles used did appear to improve the legibility of the robot, there is still room for further improvement. In order to improve the legibility further, it is important to provide useful cues regarding the internal state of the robot, such as its intentions. However, care should be taken to avoid accidentally creating misleading cues (Kruse et al., 2014). In line with the goal of the project, minimal adjustments to the robot, while creating a maximum impact, are preferred.

Add-ons such as light or sound fit these criteria. As the transport robot operates in noisy industrial settings, add-ons using sound are not very obvious. Adding light signals, on the other hand, does not require extensive adjustments to current transport robots and AGVs. Light signals are rather easy to detect for humans and in addition they attract attention. Furthermore, they are readily interpreted as an attempt to communicate (Fernandez et al., 2018). Participants in the current study indicate, that the legibility or the predictability of the robot could be improved by adding light signals. They thought of turn signals or brake lights, similar to those used on cars, or to use a projection to show its direction and purpose. Several studies already focussed on adding light interfaces to, for example, cars or drones (Habibovic et al., 2018; Szafir et al., 2015) or use projection to communicate directions (Chadalavada, 2016; Chadalavada et al., 2020). Therefore, adding communicative light signals to a transport robot is an interesting option to explore further. However, it should be taken into account that communicating the intention of a transport robot is more complex than adding a simple turn signals, since these are difficult to interpret when detached from the context of cars (Fernandez et al., 2018).

The user tests were performed in a in a public space at the university, which is not a very realistic working environment of a transport robot. Using a scaled radio-controlled car with the chasing inspired by the looks of a MiR100 in combination with the Wizard of Oz method is a relative simple method to test complex robot behaviour with users (Dahlbäck et al., 1993; Walters et al., 2005). However, the chasing and scaled size of the mock-up transport robot used may have influenced the results. The slightly smaller scale may, for instance, appear friendlier or less threatening than the actual MiR100. Additionally, simulating consistent robot behaviour is difficult for a human operator, even in similar situations (Walters et al., 2005). Using the Wizard of Oz method may have led to inconsistencies between the sessions. Additional experiments should take place in a more realistic setting, using actual transport robots or AGVs. Further, it is advisable to explore the possible confounding of the concepts legibility and predictability.

6 CONCLUSION

To make the behaviour of transport robots more legible and predictable, one needs carefully thought out design principles. Two general design principles were examined here: (1) use analogies from nature and (2) adhere to social rules. The effects of using natural walking speed, timely deceleration (*slow in and slow out*), a curved path (*arched trajectory*), in combination with swerving to the right, show positive effects for the user experience and improve the legibility of the transport robot. Future research may explore the distinguished effects of these variables.

In order to further improve the legibility of transport robots and AGVs communicative light signals could be used to convey intentions. However, more research is needed to determine which signals are most appropriate to ensure intuitive interaction in an industrial setting. Applying proven principles will contribute to intuitive interaction between humans and collaborative robots, and promote effective teamwork.

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