You're Doing It Wrong! Studying Unexpected Behaviors in Child-Robot Interaction

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Abstract. We present a study on the impact of unexpected robot behaviors on the perception of a robot by children and their subsequent engagement in a playful interaction based on a novel "domino" task. We propose an original analysis methodology which blends behavioral cues and reported phenomenological perceptions into a compound index.
While we found only a limited recognition of the different misbehaviors of the robot that we attribute to the age of the child participants (4-5 years old), interesting findings include a sustained engagement level, an unexpectedly low level of attribution of higher cognitive abilities and a *negative* correlation between anthropomorphic projections and actual behavioral engagement.

1 Introduction

1.1 Towards Sustained Engagement

Engagement is a metric that has been extensively used and studied both in HRI and during interactions with other agent-like systems. It has been defined from several perspectives. For example [11] define engagement as *"the process by which two (or more) participants establish, maintain and end their perceived connections"*. A definition of long-term engagement is proposed by [1]: *"the degree of involvement a user chooses to have with a system over time"*.

Different possibilities to foster engagement (both short- and long-term engagement) in HRI have been explored, in particular with social robots. A lot of research has moved toward creating sophisticated emotional models which cause complex robot behavior. [6] studied the long-term engagement of children with a chess playing robot that adapted its behavior to the children and showed empathy toward them. The authors found that empathetic robots are more likely to engage users in the long-term and they proposed several guidelines for designing such artificial companions. Other works [1,10] have shown that simpler ways to enhance engagement may as well be effective: [1] describe a series of longitudinal studies on engagement with an agent-like system. They demonstrated that user engagement with an interface agent can be increased using relatively simple techniques and manipulations that make the agent more life-like and human.

For instance, when the agent showed variations in its behavior, participants were more engaged and reported a desire to continue interacting with the agent.

Similarly, looking at short-term engagement, [10] found that a simple manipulation of the robot's behavior can lead to greater engagement. The authors let participants play several rounds of the rock-paper-scissors game with the robot (the playfulness of the scenario seems important). When the robot was cheating from time to time, participants tended to ascribe intention to the robot what in turn led to greater engagement in how they were interacting with the robot. The authors observe that *"any deviation from expected operation is sufficient to create a greater degree of engagement in the interaction."*. Along those lines, we also suggested in our model of the dynamics of anthropomorphism in HRI [8] that *disruptive behaviors* may lead to increased anthropomorphic projections and possibly increased engagement.

Based on this previous research, we explore in this study how to sustain children's engagement with the *Ranger* robot [9] by manipulating the behavior of the robot so that it appears *unexpected* to the children. The main outcomes of this research are 1) a new experimental task that suggests and contrasts three types of mis-behaviors, with different cognitive correlates, 2) a mixed technique, blending behavioral cues and reported phenomenological perceptions, to assess the robot perception in terms of both engagement and human-likeliness, 3) an actionable approach based on the introduction of mis-behaviors to support child-robot engagement, 4) and a first experimental cue that anthropomorphic perceptions do not necessarily correlate with actual engagement.

1.2 Design and Hypotheses

In a playful scenario which was set up in a laboratory environment, 26 children aged 4-5 years (M=4.46) were assembling a domino game together. Each group consisted of two children and the *Ranger* robot, which was used to transport domino tiles between the two children.

Ranger usually behaved correctly (expected behavior), coming over to a child after being called and delivering the domino tile to the other child. However, in pre-defined rounds, *Ranger* showed unexpected behavior when a child called the robot. We defined three different types of *misbehavior* that were tested in a between-subjects study design:

- The robot gets **lost**: When called by the child to come over, the robot goes wrong, without any observable reason, and remains at the wrong location. We expect this to be perceived as a mechanical malfunction (a bug or system error which causes the robot to not work correctly), and hypothesise decreased attributions of human-likeness to the robot.
- The robot **disobeys**: When called by the child to come over, the robot shows that it refuses to obey by literally "shaking its head" and becoming red. The robot then goes to a wrong location and remains there while it continues to shake its head. We expect the disobey behavior to be perceived as the robot having an explicit *"own will"*, and we assume this leads to increased attributions of human-likeness (ascribing intentionality) to the robot.

– The robot makes a **mistake**: When called by the child to come over, the robot goes wrong but recognises its mistake and repairs. We expect this to be perceived (explicitly) as *"to err is human"*, and (implicitly) as the robot being endowed with a certain level of introspective capabilities (it was able to recognise its own error). In this condition, we assume increased attributions of human-likeness to the robot.

We analysed children's reaction focusing on two main aspects. On one hand, children's **behavior** (their reactions) toward the unexpected robot behavior was studied in terms of **active engagement** with the robot. On the other hand, we analysed children's **perception** of the robot in term of **anthropomorphism** – the attribution of human-like characteristics, such as cognitive abilities and the ability to show intentions. We assumed that in general a robot that behaves unexpectedly from time to time can promote engagement and lead children to attribute intention to it. Based on the related work we formulate the following two hypotheses:

– **Hypothesis 1**: Children show more engagement toward a robot that behaves unexpectedly from time to time compared to a robot that always behaves correctly.
– **Hypothesis 2**: Children perceive a robot that (tentatively) displays intention or cognitive abilities as more human-like than a robot that appears to have a system error, *i.e.* the disobeying robot and the robot that makes a mistake will be more anthropomorphized than the robot that gets lost.

Our research questions deal with both children's observable behavior and their perception of the robot. We propose to consider a novel combination of these two aspects into a synthetic *compound index* that measure *anthropomorphic projections* (*i.e.* the attribution of human-like characteristics) to the robot by the children.

Based on literature suggesting that a social relation to a robot (anthropomorphism is a specific type of social relation) reflects an increased engagement and can be effective in sustaining interaction, we formulate therefore a third hypothesis:

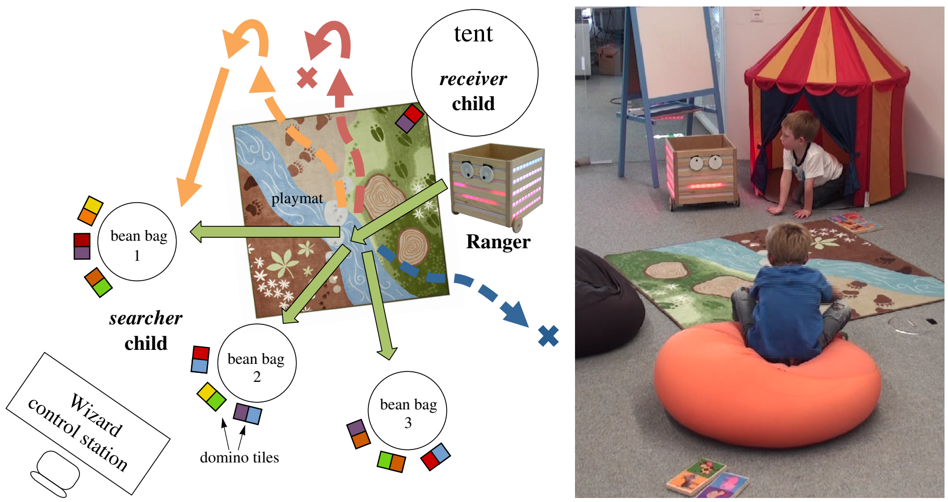
– **Hypothesis 3**: Anthropomorphic perception of the robot positively correlates with the level of engagement in the interaction.

2 Research Methodology

2.1 Experimental Setting

The interaction scenario consisted in two children who play the dominos together, with the help of a remotely controlled robot (Wizard-of-Oz setup). Figure 1 pictures the experimental setup.

The challenge for the children consists in collecting domino tiles spread over the room, hidden behind beanbags (task of the *searcher* child), getting the robot



(a) Experimental setting (b) Example in disobey condition

Fig. 1: **Experimental setting** The solid green arrows show the robot's path for the *correct* behavior. The blue arrow visualises a possible *lost* path, where the *Ranger* stops and remains at a wrong spot. The yellow arrows reflect a possible *mistake* path, where the robot goes wrong but then turns back and goes to the child. The red arrow visualises a possible *disobey* path where the robot goes wrong, then turns toward the child but stays at a wrong position.

to carry to the second child, and finally assemble the tiles and decide for the next tile to fetch (tasks of the *receiver* child).

The *Ranger* [9] is a wheeled box (27 x 37 x 37 cm) with partial wooden surface. It can drive on a flat surface, move its eyes and eyebrows, display colours (LED arrays) and light patterns, and play sounds through Bluetooth speakers. The robot was controlled by a human wizard, who was in the same room (see Fig. 1 – only one group asked at the beginning of the experiment if the wizard was the one actually controlling the robot. This did not seem to subsequently influence their behavior). In total, 13 pairs of children (n=26) participated: 16 boys and 10 girls, 4-5 years old (M=4.46, SD=0.45), all French-speaking.

The game (that lasted in average 13min 43sec per group of children) was divided in a total of 14 runs that correspond each to the delivery and assembling of one domino tile. At each run, the robot exhibits one out of the four possible behaviors previously presented: *correct*, *lost*, *disobey* or *mistake*. The game starts with one domino tile in front of the tent, where the receiver child stays and assembles the domino chain. The receiver child asks the searcher child for a specific tile, *e.g.* a tile with a donkey, the searcher child looks for the corresponding tile and sits down on the closest beanbag. When called by the searcher (*"Robot, come here!"*), the robot starts moving, crosses the river carpet, and comes over to the searcher on the beanbag. The searcher child puts the domino tile into the robotic box, and the robot then goes back to the receiver child in the tent which takes the tile and assembles it. The *run* is over, and a new *run* starts when the receiver asks the searcher for the next domino tile.

The first 5 runs (*1.1* to *1.5*) were used to set the baseline and the robot always behaved correctly. The children then switched the roles receiver/searcher and in the 9 remaining runs (*2.1* to *2.9*), the robot showed one of the misbehaviors (*lost*, *disobey* or *mistake*) at the 3^{rd} and 4^{th} run as well as at the 7^{th} and 8^{th} run (see axis x of Fig. 2).

During the misbehaving runs, the behavior of the robot is manipulated in three possible ways, represented on Fig. 1. In the **lost** condition, the robot goes to a wrong position and remains here, behaving (yellow light pattern) as if it were correctly in front of the child. In the **disobey** condition, the robot stops mid-way, displays a red pattern and produces a repeated "annoyed" sound. It finally moves toward a wrong position and remains there, facing the child. In the **mistake** condition, the robot starts like for the *lost* behavior, but after a few seconds, turns back, blushes and finally reach the correct position, in front of the child.

2.2 Data Collection

The **perception of the robot** by the children has been captured through two audio-recorded semi-structured interviews which took place between run *1.5* and *2.1* and at the end of the experiment (a short preliminary interview was also conducted to explain the game and assess the expectations of the children toward the robot). Then, the **children's behavior toward the robot** (*i.e.* the child-robot interaction) has been captured in the video recordings by annotating a set of actions.

Perception – Semi-Structured Interviews One pre-interview and two interviews were conducted with the children. Due to the age of the participants, we set up the interviews like a casual conversation and we did not separate the two children. We paid attention to not "put words in children's mouth". Consequently, though we re-phrased and repeated some questions, we accepted when they said they would not know or when they did not respond at all.

In designing our interview script and selecting relevant questions, we took inspiration from previous work on child-robot interaction and children's perception of robots ([5,7,12]). For instance, we applied and adapted some of the *constructs* and example questions from the questionnaires used in [5] and [12]. A *construct* addresses a specific factor (topic) that can be measured by several questions. For instance, the construct "cognitive connections" (using Flavell's terminology [4]) considers the robot's ability to hear and to see (perceptual skills), as attributed by the children. The construct "moral standing" and the related question was taken from [5].[3] Similarly, we grouped questions according to the specific constructs that they evaluate.

With several recurring questions in the first and second interview, we wanted to see the differences in children's perception of the correctly behaving and unexpectedly behaving robot. We planned to use these two interviews as a within-subject measurement, however, this did not fully work out because children's responses were not always accurate, not comparable one by one, and children did not always give an answer. Hence, we did not craft a full word-by-word transcript but instead we isolated the key statements that were relevant and used them to build the compound index presented below (section 2.2).

Interaction – Action Coding We annotated the behaviors of the children in the video records, and coded the salient actions that reflected engagement toward the robot (the coding scheme has been inspired from [3]): **touch** (the box is touched, *e.g.* petted or caressed); **talk** (all direct verbal interactions, except for calling it to come and pick a domino tile, since children were requested to perform this action anyway); **show** (show something to the robot); **misuse** (kick the robot, poke it in its "eye", try to climb on or inside the box, drive/push the robot around, stop the robot's wheels with a foot); **look** (when a child looks *at the experimenter* due to confusion caused by the robot; look is not coded when the experimenter asks a question to the child); **gesture** (gestures are used to communicate/interact with the robot, *e.g.* pointing gestures, waving at the robot). Figure 2 shows the distribution of these actions over the different runs, summed over the three condition.

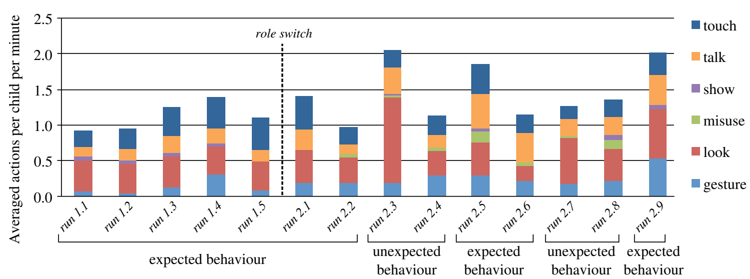


Fig. 2: **Number and type of actions for each run** (n=480, spontaneous actions). Generally, the number of actions does not decrease over time (from run 1.1 to run 2.9). The first 7 runs correspond to the *expected phase*, the second 7 runs correspond to the *unexpected phase*. Especially during run 2.3, the first time when the robot showed an unexpected behavior, children tended to *look* more at the experimenter. During the unexpected phase, also *talk* and *gesture* seem to be increased.

[3] According to [5], *moral* refers to considerations based on an artifact's physical or psychological welfare, and virtue (whether the artifact deserves care). An attribution of moral standing reflects, for instance, that the robot engenders moral regard, is morally responsible, blameworthy, has rights or deserves respect.

Compound Index of Anthropomorphism Because the tendency to anthropomorphize manifests itself both in terms of perception and behavior, we propose to build a compound index that brings both children's perception of the robot (post-measurement) and their behavior toward it (in-the-moment measurement) together. We build the index by attributing points for each anthropomorphic *perception* of the robot and for specific kinds of human-like *behavior* toward the robot, using the following grading scheme:

- *Percept.* Ascription of **mental states / feelings**: *2 points* for agreeing that *Ranger* can be happy or sad; *2 points* for attributing *Ranger* with hunger or tiredness.
- *Percept.* Ascription of **cognitive abilities / intention**: each *0.5 points* for ascribing seeing and hearing ability; *1 point* for agreeing that *Ranger* can go out the door by itself; *1 point* for disagreeing that *Ranger* always obeys; *1 point* for agreeing that *Ranger* can do something silly.
- *Percept.* Ascription of **sociality / companionship**: *1 point* for agreeing that *Ranger* can be a friend.
- *Percept.* Ascription of **moral standing**: *1 point* for disagreeing that *Ranger* be left alone at home.
- *Percept.* Other **anthropomorphic statements**: *1 point* for anthropomorphic reason for *Ranger*'s misbehavior; *2 points* for anthropomorphic reason for not leaving *Ranger* alone (*e.g. "It would be sad"*).
- *Behav.* Use of **direct speech**: *1 point* (not considering *calling* the robot to come over).
- *Behav.* Use of **polite formulations**: *1 point* (*e.g. "thank you* Ranger*"* or *"please* Ranger *…"*).
- *Behav.* Use of **social or pointing gestures**: *1 point* (*e.g.* waving at the robot).

The balance of the grading scheme is open to debate: for instance, we did not consistently assign 1 point to each item, but assigned points between 0.5 and 2 points depending on our perception of how a given item reflect a higher level of anthropomorphic perception of the robot (for instance, ascribing the ability to see and hear was suggested by the design of the study, and we cannot assert it really reflects the explicit projection of cognitive skills). This issue is however mitigated by our use of this compound index as a *relative* metric (comparison between conditions) and not an absolute value.

3 Main Findings

This section present our main findings, interleaving the analysis of perceptions (interviews) with behavioral data (action annotations).

3.1 Misbehavior Recognition

As stated in the introduction, we had hypothesised that the *disobey* behavior is perceived as the robot intentionally not doing what it should do. The *mistake* behavior was intended to show that the robot can do a mistake but is aware of it and able to repair its mistake, which should also lead to the perception of intentionality and introspective skills. Contrary, we expected that the *lost* condition is perceived as a malfunction or bug of the robot. In the second interview, after the robot had misbehaved, we asked children whether the robot always did what they wanted it to do. Most children disagreed and said they noticed something strange.

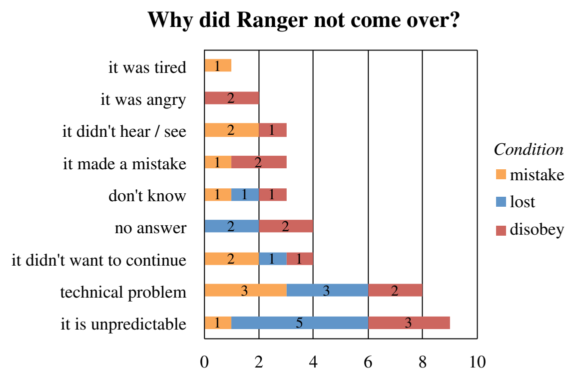


Fig. 3: Multiple answers were possible to the question why the robot did not come over, and we received 37 answers.

When asked why they thought the robot had not always come over to them, 4 of the children did not reply. The remaining ones gave a variety of reasons (Fig. 3). The most common answer (9 of 37 replies) was that the robot is somehow *unpredictable* in what it is doing and that it could go *"no matter where"*[4] because *"with robots you have these kind of problems, they do no matter what"*. 8 replies related to *technical problems* (including *broken parts*), suggesting that children perceived the misbehavior as unintended by the robot. Two of the children who had interacted with the disobeying robot said *Ranger* was *angry*, which none of the children in other conditions replied. 13 out of 26 children appeared to ascribe intentionality precursors to *Ranger* explaining that it *did not want to continue* carrying domino tiles or that it *"did something silly"*[5].

[4] We translated children's answers from French to English. For some expressions the meaning and connotation of an expression may not be the same. We understand *"partir dans tous les sens"* as "to go off in all possible directions" and hence interpret this reflects viewing the robot as being unpredictable.

[5] We understood *"faire une bêtise"* as "to do a silly thing" in the sense of making a mistake.

3.2 Attribution of Intentionality

One of the central points of this study was to investigate to what degree children attribute intention and cognitive abilities to the robot. In the first interview after children had interacted with the correctly behaving robot we asked three questions to assess how far they ascribe **intention** to it. One of these questions was whether they believed *Ranger* could go out the door by itself. A majority of 16 children answered negatively, which suggests that they initially do not ascribe intention to the robot. The two other questions were whether Ranger would always obey and whether *Ranger* could do a silly thing (Fig. 4). These two questions were asked again later after children had interacted with the unexpectedly behaving robot.

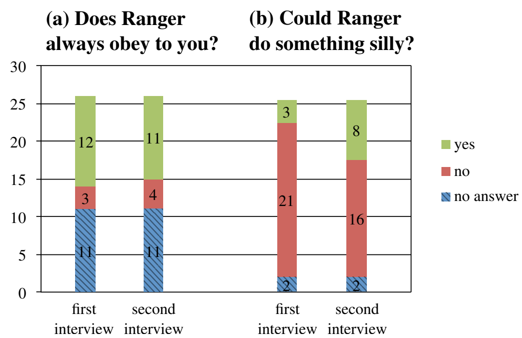


Fig. 4: **Attribution of intention to *Ranger*.**

In the first interview, 12 out of the 15 children who provided an answer believed that *Ranger* does always obey to them. Asked whether the robot could do something silly, a large majority of 21 children out of 24 replied negatively: it appears that after children the first round of interaction (with the **correctly behaving robot**) the children does **not** generally **ascribe intention** to the robot.

After interacting with the misbehaving robot (second interview), most of the children still believed that *Ranger* always obeys to them. However, 8 children (previously 3) think that *Ranger* could do something silly. One child in the *disobey* condition had changed his answer, and two in each the *mistake* and *lost* conditions: even with an **unexpectedly behaving robot** children do **not necessarily ascribe intention** to the robot. It seems that some children did not interpret the misbehavior of the robot as intentional but more like a technical problem or mistake. For instance, even after the robot misbehaved by *disobeying*, the majority of the children in this condition was still convinced that the robot could not do a silly thing. It is however interesting to note that children tend to ascribe cognitive abilities to the robot, like the ability to see and hear but not intention. We interpret this as children perceiving the robot as being able to process sensory information but not being able to make decisions on its own.

3.3 Engagement

We found a significant difference between the average of engagement actions (Fig. 2) carried out during the first 7 runs (correct robot behavior) and during the second 7 runs, when the robot behaved unexpectedly ($F(1,36)=5.1$, $p=.03$). In all three conditions, children carried out more engagement actions with the unexpectedly behaving robot. Importantly, no interaction effect was found between the two phases of interaction (expected / unexpected) and condition ($F(2,36)=1.2$, $p=.31$): the robot's failure mode does not seem to impact the level of engagement.

In general, this finding **supports our first hypothesis**: children show more engagement toward a robot that behaves unexpectedly from time to time compared to a robot that always behaves correctly.

It must be noted that the novelty of the robot plays an important role. Our findings do not directly address the issues of long-term usage and are effectively focused on short-term *engagement*, which is a pre-requisite for long-term usage.

3.4 Anthropomorphic Projections

On average, *Ranger* was moderately anthropomorphized by the children. 8 of the 13 groups had an index of 8 or higher, evenly spread over the three conditions (table 1). However, the mean index of anthropomorphism in the three conditions varied, with the *mistake* and *lost* condition leading to a higher index than the *disobey* condition. This finding suggests that the disobeying robot was *less* anthropomorphized than the other two robot behaviors, which speaks **against our second hypothesis**. We had expected that the disobeying behavior is perceived as an intentional action which we assumed would lead to increased anthropomorphism. This was not the case. The slight difference between the *lost* and *mistake* robot was also expected in the opposite direction and the *lost* robot was overall the one eliciting the highest level of anthropomorphism (the robot's "helplessness" may have lead to this). This is also reflected in children's behavior: with the lost robot, children looked more often at the experimenter than in the other condition, which suggests that they could not fully make sense of the robot's behavior, and the fact of not being able to understand (and hence predict) a robot's behavior is likely to increase anthropomorphism.[6]

We hypothesised that children who interact a lot and are probably more engaged with the robot also perceive the robot as more human-like. Data suggests the opposite, however. As shown in Fig. 5, **the more a group showed engagement in the interaction, the less they anthropomorphized the robot**. This is a key result, which was against our initial assumption. A possible

[6] One of the cognitive / psychological explanations for anthropomorphism is that people want to make sense of something they do not understand and then tend to anthropomorphize this something (human traits are a good source of making attributions because this is what people understand best – themselves and other humans). For more details the reader may refer to [2].

Table 1: **Resulting anthropomorphism index** per condition

	M	SD
lost	8.31	0.59
disobey	6.5	3.68
mistake	7.94	1.74

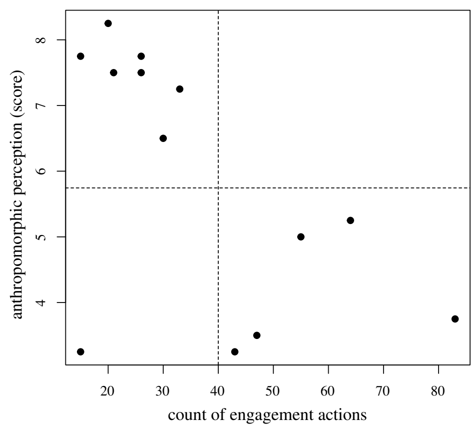


Fig. 5: **Anthropomorphic perception of the robot versus engagement actions per pairs.**

interpretation is that children who interact more with the robot understand better how it works, they are more familiar with it, and as such the robot appears less "mystical" to them, and they hence do not need to anthropomorphize it. On the contrary, the cluster of groups that do not interact much but anthropomorphize the robot more, is quite homogeneous, and may reflect a certain fear of interacting with a robot that would look to them too human-like. This raises the question how far anthropomorphism (as a special kind of social engagement) really helps in sustaining interaction. This is a critical point because most of the short-term investigations suggest that anthropomorphic design and human social cues emitted by a robot foster engagement and acceptance. What if this is not true for continued interaction, and thus for the long-term? We need to remain modest here: while we found a significant *negative* correlation between engagement and anthropomorphism in the data pictured on Fig. 5 (r(11)=-0.56, p=.05), we have to be careful about our interpretation, due to the small sample size (13 pairs), and we suggest to investigate the aspect further in future research.

4 Conclusions and Future Directions

As hypothesised, we found that in a playful scenario where 4-5 year old children play domino together with a robot, the robot seems to be more engaging when it shows some misbehavior compared to when it always behaves as expected (notwithstanding the impact of a novelty effect).

Regarding the design of our three conditions (*lost*, *disobey*, *mistake*), we cannot conclusively affirm whether children perceived the unexpected robot behavior as a malfunction (something that happens to a machine) or as being intended and based on a motivation (something related to a social entity). Children stated both, when asked why the robot had misbehaved. Some referred to *"a technical problem"* while others said the robot *"is tired"* or it *"doesn't want to carry domino tiles any more but rather go on a tour outside"*. While our manipulations were not as clearly perceived as we expected for the age range of the subjects, we still believe these three conditions (mechanical malfunction – the *lost* condition, vs. explicit intentionality – the *disobey* condition, vs. implicit intentionality – the *mistake* condition) are relevant and we suggest to replicate a similar study with slightly older children.

Still, we did not find support for our second hypothesis which stated that children perceive a robot showing intention or cognitive abilities as more human-like than a robot that appears to have a system error. While this may be due to the study setup and the fact that children did not interpret the robot misbehavior in the conceived way, our findings seem to suggest the contrary to our hypothesis. A robot that appeared to do a *mistake* or to be *lost* was more anthropomorphized than a robot that *disobeyed*.

Another outcome of this study is the initial application of an compound index of anthropomorphism to assess children's anthropomorphic projection onto robots. This index considers both behavioral and phenomenological aspects, and it suggests, in our experiment, that children tend to conditionally anthropomorphize the robot. Higher indexes of anthropomorphism were found in the *lost* and *mistake* condition which was against our hypothesis.

Interestingly, data suggests that anthropomorphic perception does not automatically elicit engagement, on the contrary. It appears that groups who interacted more with the robot perceived it as less human-like. This raises an important question for the human-robot interaction community: to what extent do anthropomorphic perceptions impact the interaction experience? Our findings here go against the intuition.

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