Does a "robot dog" need legs, ears, and tail? A comparative analysis of intention- and emotion-attribution to Miro-E and Unitree Go1

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Abstract

The study reported in this paper analysed the effectiveness and acceptability of ethologically inspired expressive behaviours implemented in two distinctively different embodiments of the zoomorphic robots Miro-E and Unitree Go1. It investigated how primary school children attribute intentions and emotions to the two robots, examining the importance of certain body-parts in human-robot interactions to convey affective states and express intentions (e.g., ears, tail, legs). 111 students aged 7 to 10 years participated in the study in a within-subject design, observing an interaction between each robot and an experimenter in small groups. Every child observed both robots interacting with an experimenter in the same scenario following an AB-BA order. After each interaction, a questionnaire was presented to each student individually. Effects of a) robot embodiment, b) dog-ownership, and c) students' age on their perception of the robots, focusing on differences between the two robots' emotionally and intentionally expressive behaviour, were analysed. Results identified significant effects of each independent variable. While the Miro-E robot was identified as expressing emotions better - underlying the importance of affective features such as ears, and a tail - there was no significant difference in children's intention-attribution to the two robots, and Unitree Go1 was selected as the preferred one over Miro-E. Despite the differences both Miro-E and Unitree Go1 reliably conveyed the intended emotions and intentions, providing further evidence for the applicability of the ethorobotics approach. Findings implied that the incorporation of zoomorphic embodiment features to express social signals could expand potential applications of these robots.

Keywords: Zoomorphic robots, Ethorobotics, Emotion- and intention attribution, Expressive robotic behaviour, Human-Robot Interaction (HRI)

Statements and Declarations: Authors declare that there are no relevant financial or non-financial competing interests to report.

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Introduction

The Ethorobotics approach

Ethorobotics is a young but fast-expanding field that uses ethological models in robot development. It applies a clearly distinguishable approach, aiming to establish a biologically inspired theory for robot design and development (Nazir et al. 2023) with the creation of credible and acceptable social characteristics for robotic agents being its primary concern (Abdai and Miklósi 2024). It has been suggested that to increase the lifelikeness, acceptability, and credibility of robotic agents, robots need to express emotions and intentions making people attribute inner states and aims to them (Breazeal and Scassellati 1999; Fong et al. 2003; Becker et al. 2005). In fact, emotion expressions of robots have been proved to facilitate human–robot interaction (Fong et al. 2003) and it is assumed that they contribute to the long-term engagement of users toward artificial agents. Interpretable expression of intentions has been suggested to be similarly important (Lakatos 2016; Holthaus et al. 2023). Previous studies provided evidence that the ethorobotics approach and more specifically, the use of dog-inspired social behaviour implemented in robots is indeed an effective medium for making people attribute emotional states (including primary and secondary emotions) and intentions to robots with various embodiments leading to more acceptable interactions (Koay et al. 2013; Lakatos et al. 2014; Lakatos 2016).

The current paper comparatively examines the effectiveness and acceptability of ethologically inspired expressive behaviours implemented in two distinctively different embodiments of the zoomorphic robots Miro and Unitree Go1, analysed in school settings with children of different age-groups.

Zoomorphic Robots and their applications

Zoomorphic robots are designed to mimic animal-like forms and behaviours. They are suggested to provide a non-threatening and engaging human-robot interaction (HRI) by intuitive communication. Unlike humanoid robots, which often face challenges like the uncanny valley effect (Coeckelbergh 2011), zoomorphic robots evoke familiarity without attempting to replicate human appearance. Their design philosophy often focuses on aligning physical form with functionality, ensuring adaptability across contexts such as therapy, education, and social robotics.

In fact, zoomorphic robots have demonstrated significant potential in therapeutic and educational settings, offering intuitive and engaging tools to support learning and emotional development, and creating safe and supportive environment for users.

In therapeutic contexts for certain user groups, zoomorphic robots may offer unique advantages in addressing both emotional and physical needs. For example, robots like Paro, modelled after a baby harp seal, are extensively used in elderly care settings to provide emotional comfort and reduce anxiety (Inoue et al. 2021). Robots such as Paro and PLEO – the latter one modelled after a baby dinosaur -

have even been proposed as substitutes for animal-assisted therapy when live animals are unavailable (Shibata & Wada 2011). Inoue et al. (2021) demonstrated Paro's effectiveness in home-based care for individuals with dementia, where it provided emotional support and improved overall well-being. Similarly, Rashid et al. (2023) found that Paro reduced behavioural and psychological symptoms while increasing sociability in older adults. Paro's success in elderly care settings underscores the broader potential of zoomorphic robots in therapeutic applications. This is further supported by recent research of Tanaka et al. (2022) investigating AIBO's applicability in an assistive role for hospitalised children that demonstrated AIBO's potential to be applied in paediatrics.

Zoomorphic robots can also serve as valuable tools in educational settings, supporting social and emotional learning for children by providing an intuitive and engaging platform for them. Recent research highlighted that children respond positively to zoomorphic robots, perceiving them as non-threatening and engaging (Barber et al. 2021). Robots like AIBO, Sony's robotic dog, have been demonstrated as a successful tool in eliciting nurturing behaviours and promoting social interactions (Fujita 2001; Melson et al. 2009). Zoomorphic robots also proved to be useful in supporting children with developmental and cognitive disorders, such as autism spectrum disorder (ASD). By simulating emotional cues in a controlled and predictable manner, robots like Miro are suitable to provide children with opportunities to practise recognising and responding to emotions. Research shows that these interactions can reduce anxiety and improve social engagement in children with ASD, offering an accessible alternative to traditional therapy methods (Prescott et al. 2017). Additionally, it could be assumed that robots like Unitree Go1 could potentially facilitate kinaesthetic learning through its dynamic mobility and animal-like design, which could enable children to participate in collaborative games and physical activities that promote teamwork and problem-solving skills. These ideas align with views of Jung & Won (2018) who emphasised the role of robotics in enhancing cognitive and emotional development in young children.

The applicability of zoomorphic robots extends beyond individual applications to their broader role in advancing HRI research. By avoiding the pitfalls of anthropomorphism and focusing on a more functional design, zoomorphic robots offer a scalable approach to addressing emotional, cognitive, and physical challenges across multiple domains.

However, while the cute and approachable designs of zoomorphic robots have succeeded in eliciting emotional responses, these robots often fail to sustain users' long-term interest due to their limited behavioural repertoire. Users quickly lose engagement when robots cannot replicate the richness of real pet behaviours, such as adaptive responses to stimuli or more complex interactions (Melson et al. 2009). This highlights a fundamental limitation of zoomorphic robots that focus on appearance without aligning it with sophisticated behaviours and functionalities.

The above limitations underscore the importance of matching a robot's appearance, behaviour, and functionality to users' expectations (Lakatos 2016; Abdai and Miklósi 2024). Hence, in the current study we investigated the acceptability of two zoomorphic robots with very different embodiments – Miro-E and Unitree Go1 – demonstrating behaviours based on ethological models to fulfil the same function of participating in a social interaction, while conveying emotions and intentions. It was analysed how the different embodiments affect users' acceptability of the two robots, and how successful each robotic embodiment is in making children attribute emotions and intentions to them.

The Miro-E and Unitree Go1 Robots

Miro-E and Unitree Go1 exemplify the diverse potential of zoomorphic robots in human-robot interaction. These robots embody distinct design philosophies tailored to their specific applications, showcasing the adaptability of zoomorphic designs to meet different functional needs.

Miro-E[1] (later referred to as Miro), developed by Consequential Robotics in collaboration with the University of Sheffield, is a biomimetic robot designed to resemble no specific animal while evoking familiarity and approachability. Its unique design incorporates expressive features such as ear movements, tail wagging, tactile sensors, and LED-based emotional displays enabling it to effectively simulate affective behaviours like happiness, sadness, and curiosity (Mitchinson & Prescott 2016; Ghafurian et al. 2022). These features make Miro particularly effective in contexts that require emotional engagement, such as therapeutic settings and education.

Unitree Go1[2] (later referred to as Unitree), developed by Unitree Robotics, stands out as a quadrupedal robot designed to prioritise dynamic mobility and physical interaction. Its dog-like design, characterised by advanced actuators, high-precision joint mechanisms, and sensors, allows it to navigate complex terrains and participate in physically engaging activities. Unlike static robots, Unitree's dynamic capabilities enable it to integrate seamlessly into tasks requiring movement, coordination, and collaborative interaction. This design makes it a potential candidate for kinaesthetic learning and physical rehabilitation.

Both robots illustrate the potential of zoomorphic designs to enhance HRI across various domains adapted to the diverse needs of different user groups.

Research Question and Hypothesis

Our research question investigated how primary school children attributed intentions and emotions to Miro and Unitree, two zoomorphic robots with distinctly different embodiments, examining the

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1 https://www.miro-e.com/
2 https://www.unitree.com/go1

importance of certain body-parts that can be used in human-robot communications to convey affective states and to express intentions (e.g., ears, tail, legs).

Our *Hypothesis 1* concerned effects of robot embodiment, focusing on differences between the two robots' emotionally and intentionally expressive behaviour. *Hypothesis 1a* was that zoomorphic robots having ears and tail are more suitable to express emotions, hence we hypothesised that children would rate Miro higher on emotion-expressional skills than Unitree. Our *Hypothesis 1b* assumed that both embodiments would be equally suitable to express intentions, and children would successfully recognise the aims of both robots based on ethologically inspired behaviour.

Hypothesis 2 assumed that dog-ownership would have an effect on children's perception of the robots, with dog-ownership potentially leading to better recognition of intentionally and emotionally expressive behaviour of zoomorphic robots, especially of the dog-like Unitree 1.

Hypothesis 3 assumed that age would have an additional effect on their perception of the robots, with younger children potentially being more enthusiastic and excited about the robots, affecting their emotion- and intention-attribution to the two robots.

Methods

Participants and context

The experiment was carried out within the context of the UK Robotics Week 2024[3]. As part of this event researchers from the University of Hertfordshire go to a local primary school to give talks and workshops and do different activities related to robotics for the children in Year 3 (7-8 year-old students), Year 4 (8-9 year-old students), and Year 5 (9-10 year-old students).

All the children enrolled in the school in Year 3, Year 4, and Year 5 participated in the activities (N = 182), but the data was only collected for 111 children, following the Ethics Approval guidelines. Number of participants according to year groups were N=33 in Year 3, N=43 in Year 4, and N=35 in Year 5. The school is a mixed school, but demographic data regarding the preferred gender was not collected for this study. Regarding dog-ownership, N=33 participants owned a dog, while N=78 participants did not own a dog.

Each year-group was allocated a specific date when they would spend a full day participating in the activities. Each day the school provided 3 different spaces utilising the available classrooms. Each classroom had multiple simultaneous activities related to robotics, including the ones presented in this

3 https://www.herts.ac.uk/about-us/news-and-events/news/2024/robotics-week-comes-to-hatfield

paper (Figure 1). To ensure that the children's first impression was not influenced by them having seen the other robot in the same room while participating in the study, Miro and Unitree were kept in different rooms.

Children would spend about eighty minutes in a classroom, where they were again broken down into smaller groups. Each of these groups focused on a different activity for about twenty minutes before having a break then rotating to the next activity until all of the children had taken part in all activities in all classrooms.

All the activities had to do with aspects of building, programming or interacting with robots, as follows:

Room 1: Programming Thymio robots with Scratch workshop, AI in nature mini-lecture, Unitree interaction.

Room 2: Robotic hardware mini-lecture, Controlling Robomaster (racing) robots, Miro interaction.

Room 3: Creating stories with Pepper interaction, Robotic toys playtime, 3D printing mini-lecture.

Every other robot used in the different activities was very different from Miro and Unitree in nature; no other zoomorphic robots were involved in the activities apart from Miro and Unitree. In addition, some of the other robots, like Pepper, used language to communicate, while others like Thymio did not socially interact at all.

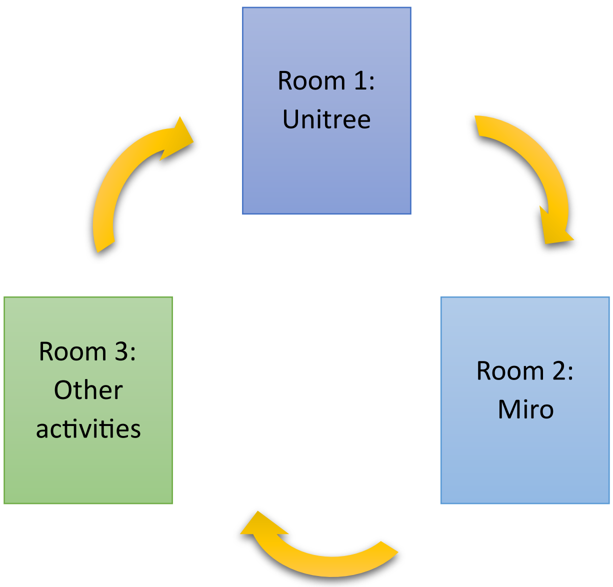

Figure 1. Children spent eighty minutes in each room rotating to the next room with multiple parallel activities in each room.

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Ethics Approval

Parental consent was obtained before collecting any data. If a child did not have parental consent, they could still participate in the activity, but no data was collected. A child could refuse to fill in the form at any time. This experiment had approval from the Ethics Committee at the University of Hertfordshire for studies involving human participants, under the protocol number SPECS/SF/UH/05674.

The setup

The setup was similar for both Miro and Unitree (Figure 2a). However, the size and risk assessment of the Unitree robot meant that there was a physical barrier made out of tables between the robot and the children, with the children sitting on the opposite side of the robot (Figure 2b). The robot was controlled by a designated operator, and no children were allowed inside the barrier when the robot was moving.

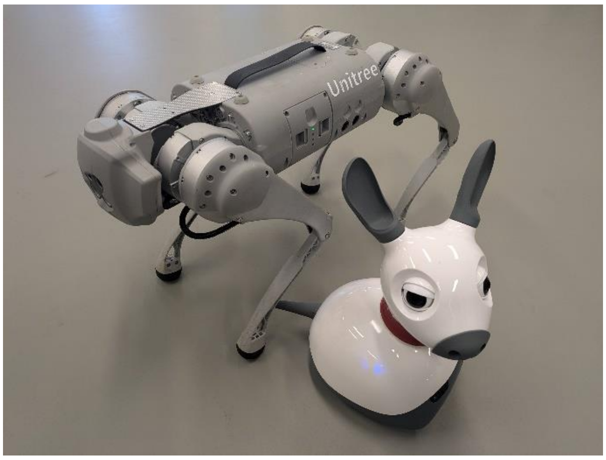

Figure 2a. The robots used in the study: Unitree Go1 on the left, Miro-E on the right.

Figure 2b. Experimental setup. Picture on the left: Setup with Miro including robot on the floor, the

small orange ball on table in the back, experimenter (standing, front left), robot controller (sitting, far right) and a person acting as a participant filling out questionnaire (sitting, centre right). Picture on the right: Setup with Unitree including robot on the floor, ball on table in the back, experimenter (standing, left) and placeholder participant filling out questionnaire (sitting, right).

Experimental Procedure

Before the interaction children received a short introduction from the Experimenter explaining that they were going to witness an interaction between the respective robot (called Miro or Unitree) and the Experimenter, following which, they were going to fill in a questionnaire about what they had seen.

During the activities with Unitree and Miro, children in groups of five or six observed the Experimenter interacting with one of these robots in the same "playing football" scenario to investigate embodiment effects on intention and emotion attribution to robots. All children sat in front row having an unobstructed view of the interaction. The experimenter did not talk to the children during the activities, nor did communicate verbally with the robot. If the children asked questions about the robots before or during the interaction, it was explained to them that they can ask all their questions after completing their second session and filling in both questionnaires. After completing their second session and filling in both questionnaires, children also had a chance to learn more about the robot they observed in their second session, and to observe further behaviours within the capabilities of the respective robot.

The study followed a within-subject design. Every child observed both robots interacting with an Experimenter in the same scenario, following an AB-BA (Miro/Unitree-Unitree/Miro) design. Due to the constraint that the children in each year group were divided into three rotating groups, however, a 50/50 split between the conditions was not possible. Instead, 2/3 of the children saw the interaction with Unitree first while the rest saw Miro first.

The scenario

A ball was placed on a shelf at a height unreachable for the robot; it was a large ball for Unitree and a smaller ball for Miro.

The interaction observed by the children between the robot and the Experimenter consisted of six main stages: 1. Robot approaching the ball; 2. Robot demonstrating excitement; 3. Robot demonstrating leading behaviour; 4. Experimenter gets the ball and gives it to the robot, the robot demonstrates happy behaviour; 5. Robot and Experimenter playing with the ball for 60 seconds; 6. Experimenter takes the ball away and places it back on the shelf, the robot expresses sadness. The detailed behaviour demonstrated by each robot in the respective stages is described in Table 1.

Expressive behaviour and leading behaviour of the robots was designed based on previous studies applying the ethorobotics approach. The robots' leading behaviour towards the Experimenter was designed based on earlier studies of Koay et al. (2013), that was one of the pioneering studies using ethological models and the behaviour of hearing dogs to design acceptable and believable robotic communicative behaviour. In the utilisation of the leading behaviour designed by Koay et al. (2013) we implemented the behaviour described in the flowchart below (Figure 3) on both robots with reasonable adjustments.

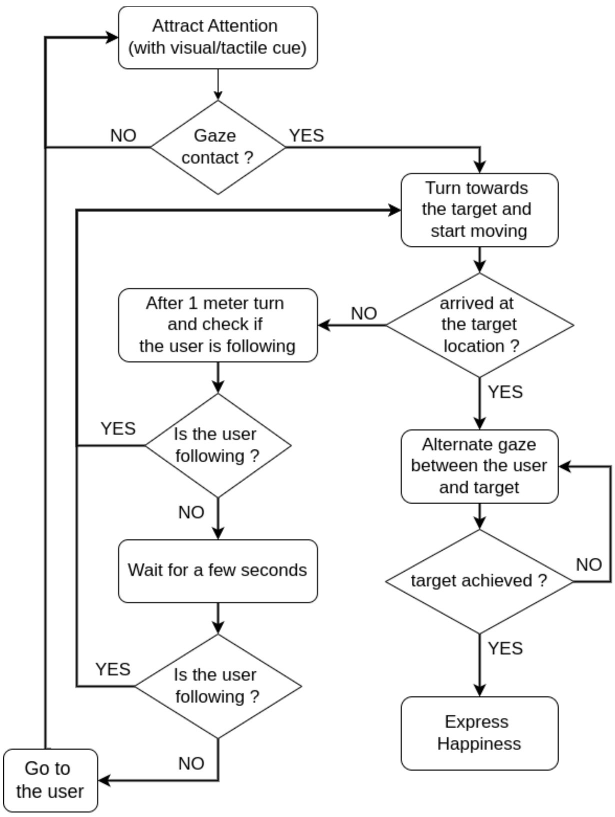

Figure 3. Flowchart for leading behaviour of both robots, Unitree and Miro (based on Koay et al. (2013)).

Reasonable adjustments meant, for example, to use different kind of behaviours to attract users' attention with Unitree and with Miro, considering the different physical capabilities of the two robots. Unitree does not have a movable head nor eyes to express eye-contact. However, Unitree could still orient towards the Experimenter and jump up and down with its front legs to attract the Experimenter's attention. Unitree could then start walking towards the ball, turning back towards the Experimenter to check whether they are following to direct attention towards the ball and express its intentions. Miro on the other hand could use head movements, "looking" into the experimenter's face, and using head turns as well as body turns in directing the Experimenter's attention towards the ball.

Emotionally expressive behaviours of the robots were based on earlier studies of Ghafurian et al. (2022), a study that specifically analysed affective behaviour of the Miro robot, and Lakatos et al. (2014) that analysed emotionally expressive behaviour of a zoomorphic robot called MogiRobi.

Table 1. Behaviour description of Unitree and Miro in each stage of the interaction.

Behaviour demonstrated	**Unitree**	**Miro**
Approaching the ball	Approaching the shelf/desk/chair where the ball is.	Approaching the shelf/desk/chair where the ball is.
Demonstrating excitement	Orienting towards the ball, wiggling hips up and down 4 times, then bouncing on the front two legs 4 times, then sitting down orienting towards the ball.	Raising the head to look at the ball, wiggling the body sideways a little, wagging the tail and expressing excited behaviour as described in Ghafurian et al. (2022): Eyes fully open; neck moving up and down very fast; head positioned upwards; ears angled forward; tail pointing up, wagging left and right widely and fast. Movements to left and right. Fast head movements between up and forward.
Leading behaviour	Based on Koay et al. (2013): Approaching Experimenter, orienting towards Experimenter, bouncing on front paws 2-3 times, orienting towards the direction of the ball, then orienting back towards the experimenter, orienting towards the	Based on Koay et al. (2013): Approaching Experimenter, looking at Experimenter, wiggling to sideways, wagging the tail, looking at the direction of the ball, then looking back at the Experimenter, looking at the

	direction of the ball (repeating this “gaze alternation” 2x in total), then starting to walk towards the ball, halfway stopping and orienting towards the Experimenter to check if follows, orienting towards the ball, orienting towards Experimenter, continuing to walk towards ball, when reaching the ball, sitting down, orienting towards Experimenter, orienting towards ball, orienting towards Experimenter.	direction of the ball (repeating this gaze alternation 2x in total), then starting to move towards the ball, halfway stopping and looking at the Experimenter to check if follows, looking at the ball, looking at Experimenter, continuing to move towards ball, when reaching the ball, looking at experimenter, wiggling sideways, wagging tail, looking at ball, looking at Experimenter while constantly wagging tail.
Experimenter gets the ball, robot expresses happy behaviour	Orienting towards Experimenter, wiggling hips up and down, bouncing on front paws 2x.	Looking at experimenter, expressing happy behaviour as described in Ghafurian et al. (2022): Eyes almost fully open; neck moving up and down in moderate speed; head forward; ears angled forward; tail pointing up, wagging left and right widely. Slight movements to left and right. Slight head movements between up and forward.
Playing with the ball for 60 seconds	Trying to chase, catch and push the ball back to the Experimenter.	Trying to chase, catch and push the ball back to the Experimenter.
Experimenter takes the ball away and places it back on the shelf, robot expresses sadness	Orienting towards ball, slowly moving away to a corner and lying down.	Looking at ball, expressing sad behaviour as described in Ghafurian et al. (2022): Eyes half closed; neck and head positioned down; ears angled outward; tail pointing down, still. Head tilting

		left and moving down. Slowly moving away to a corner.

Once the children have observed the interaction, they filled in a questionnaire. Every child filled the questionnaire individually at a pre-allocated spot. The questionnaire included questions about the liveliness of the robots, whether children would consider them as a companion/friend/machine, whether they thought the robots had intentions and emotions, what they thought the robot wanted, what emotions did they think the robot expressed if any when it got the ball, and when the ball was taken away etc. After the second session children were further asked about their preferences between the two robots. In addition, there were also questions asking children if they had any pets, and dogs specifically. Questionnaire items used as dependent measures are described in Table 2, questionnaires are also attached to the paper as Supplementary material in the format they were presented to the children.

Table 2. Questionnaire items used as dependent measures

Questionnaire after session 1	**Questionnaire after session 2**
1. Have you got a pet at home? (Yes; No)	1. Have you got a pet at home? (Yes; No)
2. If so, what kind of pet do you have? (Dog, cat, rabbit, other)	2. If so, what kind of pet do you have? (Dog, cat, rabbit, other)
3. How easy was it to understand the robot? (5-point Likert scale from "Very hard" to "Very easy")	3. How easy was it to understand the robot? (5-point Likert scale from "Very hard" to "Very easy")
4. Did you think the robot wanted to request something from the researcher? (5-point Likert scale from "Definitely no" to "Definitely yes")	4. Did you think the robot wanted to request something from the researcher? (5-point Likert scale from "Definitely no" to "Definitely yes")
5. If yes, what did you think the robot wanted?	5. If yes, what did you think the robot wanted?
6. Did you think the researcher understood the robot well?	6. Did you think the researcher understood the robot well?

(5-point Likert scale from "Definitely no" to "Definitely yes")	(5-point Likert scale from "Definitely no" to "Definitely yes")
7. Did the robot show any emotions when it got the ball? (Yes, it was happy; Yes, it was excited; Yes, it was afraid; Yes, it was sad; It did not show any emotions)	7. Did the robot show any emotions when it got the ball? (Yes, it was happy; Yes, it was excited; Yes, it was afraid; Yes, it was sad; It did not show any emotions)
8. Did the robot show any emotions when the researcher took the ball away? (Yes, it was happy; Yes, it was excited; Yes, it was afraid; Yes, it was sad; It did not show any emotions)	8. Did the robot show any emotions when the researcher took the ball away? (Yes, it was happy; Yes, it was excited; Yes, it was afraid; Yes, it was sad; It did not show any emotions)
9. The robot is more like a: friend, toy, companion or machine?	9. The robot is more like a: friend, toy, companion or machine?
10. Would you like to have a robot like this at home? (5-point Likert scale from "Definitely no" to "Definitely yes")	10. Would you like to have a robot like this at home? (5-point Likert scale from "Definitely no" to "Definitely yes")
11. Do you think the robot is alive? (5-point Likert scale from "Definitely no" to "Definitely yes")	11. Do you think the robot is alive? (5-point Likert scale from "Definitely no" to "Definitely yes")
12. Do you think the robot has its own ideas? (5-point Likert scale from "Definitely no" to "Definitely yes")	12. Do you think the robot has its own ideas? (5-point Likert scale from "Definitely no" to "Definitely yes")
13. Do you think the robot has its own emotions? (5-point Likert scale from "Definitely no" to "Definitely yes")	13. Do you think the robot has its own emotions? (5-point Likert scale from "Definitely no" to "Definitely yes")
14. What do you think the robot behaved like, an animal or a machine?	14. What do you think the robot behaved like, an animal or a machine?

	15. Which robot did you like more? (Miro; Unitree)
	16. Which robot did you think expressed what it wanted more clearly? (Miro; Unitree)
	17. Which robot did you think expressed its emotions more clearly? (Miro; Unitree)

Results

Statistical analysis

R was used for the statistical analysis. Since we collected ordinal and nominal questionnaire data, non-parametric procedures were used for the data analysis, without corrections. Paired Wilcoxon signed rank test was used to identify effects of the robot embodiment (i.e. Miro v Unitree) for ordinal data in repeated measures, e.g., questions about how much each robot expressed emotions. This test has been applied for the whole group and individual sub-groups of dog-owners and year groups. Kruskal-Wallis test with pair-wise post-hoc tests was used to examine the effects of non-repeated measures (year group and dog ownership) within each robot embodiment individually. If this test showed an effect in groupings of more than two (i.e. year groups), it was followed up by pairwise Mann-Whitney-U (Wilcoxon rank sum) tests to investigate which of the individual pairs were showing differences (i.e. between what years the differences occurred exactly). χ^2 tests were used to analyse nominal questionnaire data, e.g., measures of choice between robot embodiments asked only after both interactions, or questions whether the robot behaved like an animal or machine.

When reporting results of statistical analyses, we report all values, i.e. $\chi 2$ and p-values, rounded to three digits after the decimal point. Following common practice, p-values above 0.05 are reported as *non-significant* results, values between 0.05 and 0.01 are described as *significant*, and values below 0.01 are given as *highly significant*. For the detailed results of all statistical analysis conducted in the study see Table 3 attached as Supplementary material.

Effects of Robot condition

As a manipulation check, children were asked if the Researcher understood the robot (5-point Likert scale). There was no significant difference in their response between Unitree and Miro, indicating that there were no perceived differences due to different Experimenters interacting with the two robots ($V = 586$ and $p = 0.107$). A very good understanding of the robots' behaviour by the Experimenter was perceived by the children in case of both robots with the researcher's understanding of Miro's behaviour rated with an average of 4.03 on the scale ranging between 1 and 5 and their understanding of Unitree's behaviour rated with 4.19, respectively.

Children identified overwhelmingly well what the robots' behaviour indicated according to the "what did the robot want" question in case of both robots with no statistically significant differences between the two groups ($\chi^2 = 0.041$, df = 1, p = 0.84) (Figure 4).

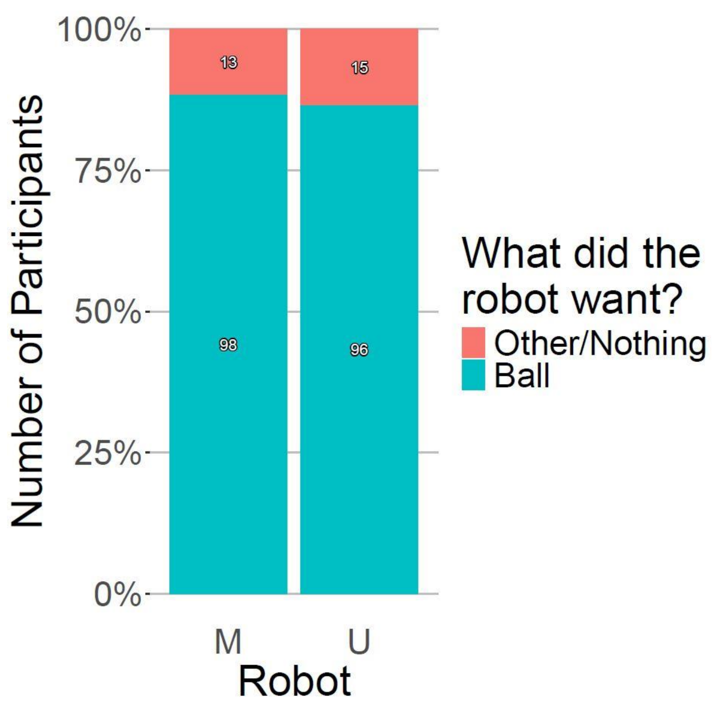

Figure 4. Effects of robot embodiment (M = Miro, U = Unitree): Children's responses to Item 5 about what they thought each robot wanted during the interaction (the ball or other things/nothing) presented in percentages of participants.

Similarly, participants reported that both robots were easy to understand, with no significant difference between the two robots (V = 1087.5, p = 0.741) and average ratings of 3.87 for their understanding of Miro and 3.86 for their understanding of Unitree on the 5-point scale (Figure 5).

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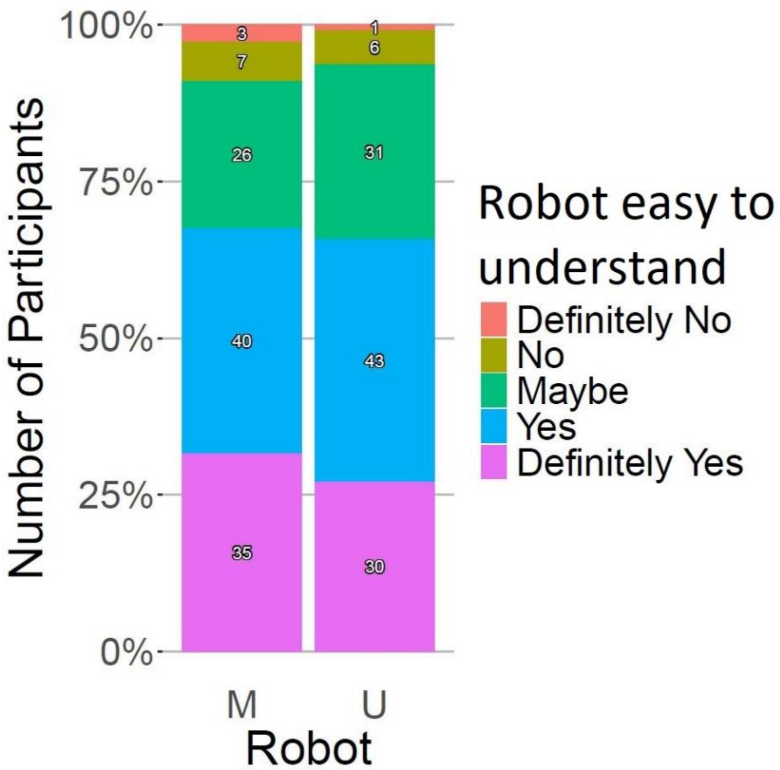


Figure 5. Effects of robot embodiment (M = Miro, U = Unitree): Children's responses to Item 3 about how easy it was to understand the robot are presented in percentages of participants.

There was no significant difference between identifying the emotionally expressive behaviour of Miro and Unitree when getting the ball – with 89.38% of children identifying Miro's behaviour as either excited or happy, and 88.07% of children identifying Unitree's behaviour the same way ($\chi^2 = 4.107$, df = 4, p = 0.392), for more details see the Supplementary material. When the ball was taken, however, children described Miro's emotion significantly differently from that of Unitree's ($\chi^2 = 11.402$, df = 4, p = 0.022) (Figure 6). In particular, a large majority of children identified Miro's behaviour as sad while this majority was smaller for Unitree, which was also frequently rated as showing no emotions.

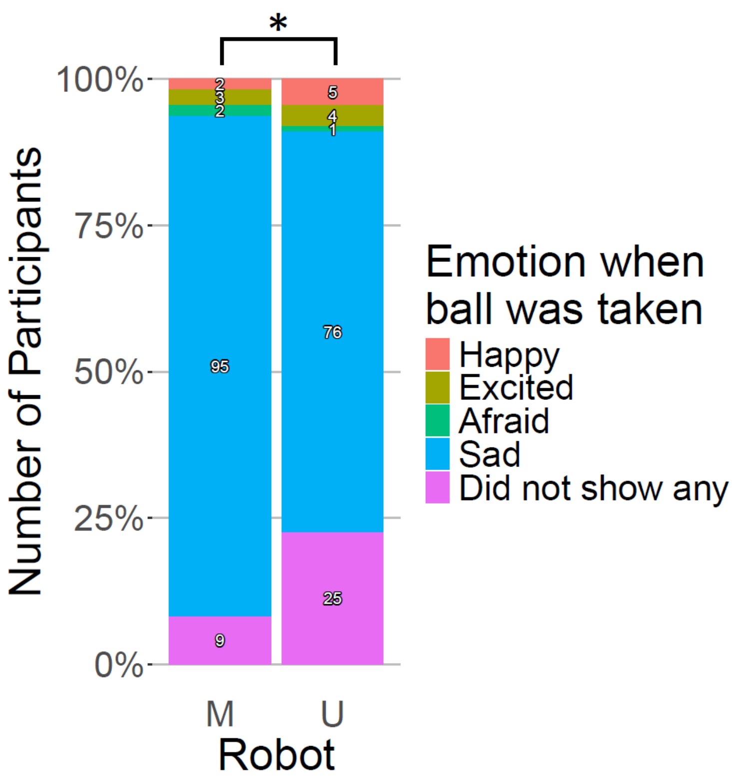
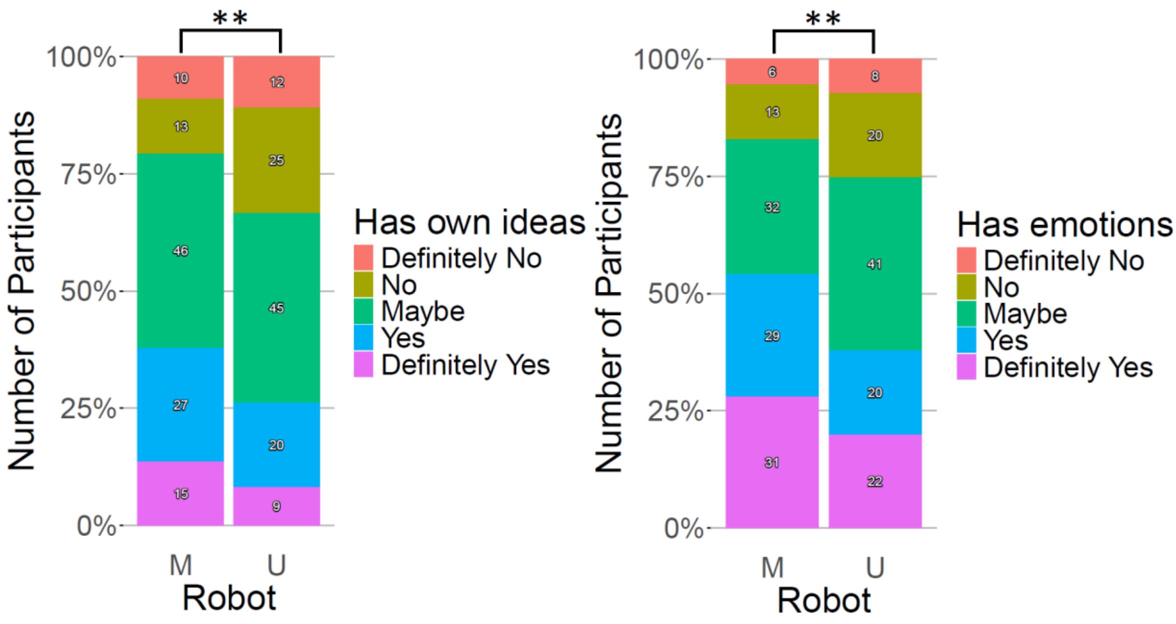


Figure 6. Effects of robot embodiment (M = Miro, U = Unitree): Children's responses to Item 7 about which emotions the robot expressed when the ball was taken from it are presented in percentages of participants (* indicates a significant difference between the robots with $p < 0.05$).

Miro was rated higher by children on the questions of having own ideas ($V = 1503.5$, $p = 0.003$) and own emotions ($V = 1125.5$, $p = 0.002$) with highly significant differences each and average ratings of 3.22 for having ideas and 3.60 for having emotions compared to Unitree with averages of 2.90 and 3.25 (Figures 7(a) and 7(b)). However, Unitree was rated significantly higher on the question whether the robot is alive ($V = 339$, $p = 0.025$) with an average rating of 2.51 compared to Miro's 2.22. Both robots' behaviour was identified by the children as animal-like with no significant difference between them ($\chi^2 < 0.001$, $df = 1$, $p = 1$).



(a) (b)

Figure 7. Effects of robot embodiment (M = Miro, U = Unitree): Children's responses to (a) Item 12 considering whether the robot has its own ideas are presented in percentages of participants (** indicates a highly significant difference between the robots with $p < 0.01$). (b) Item 13 considering whether the robot has its own emotions are presented in percentages of participants (** indicates a highly significant difference between the robots with $p < 0.01$).

When children were asked to compare the two robots directly after completing both sessions - instead of rating them in each session individually – in line with the above results, Miro was selected highly significantly more often as the one better expressing emotions ($\chi^2 = 9.991$, df = 1, $p = 0.002$), while Unitree was selected significantly more often as the preferred robot over Miro ($\chi^2 = 4.046$, df = 1, $p = 0.044$). There was no significant difference considering the question: which robot expressed its intentions better ($\chi^2 = 0.225$, df = 1, $p = 0.635$) (Figures 8 (a) and 8(b)).

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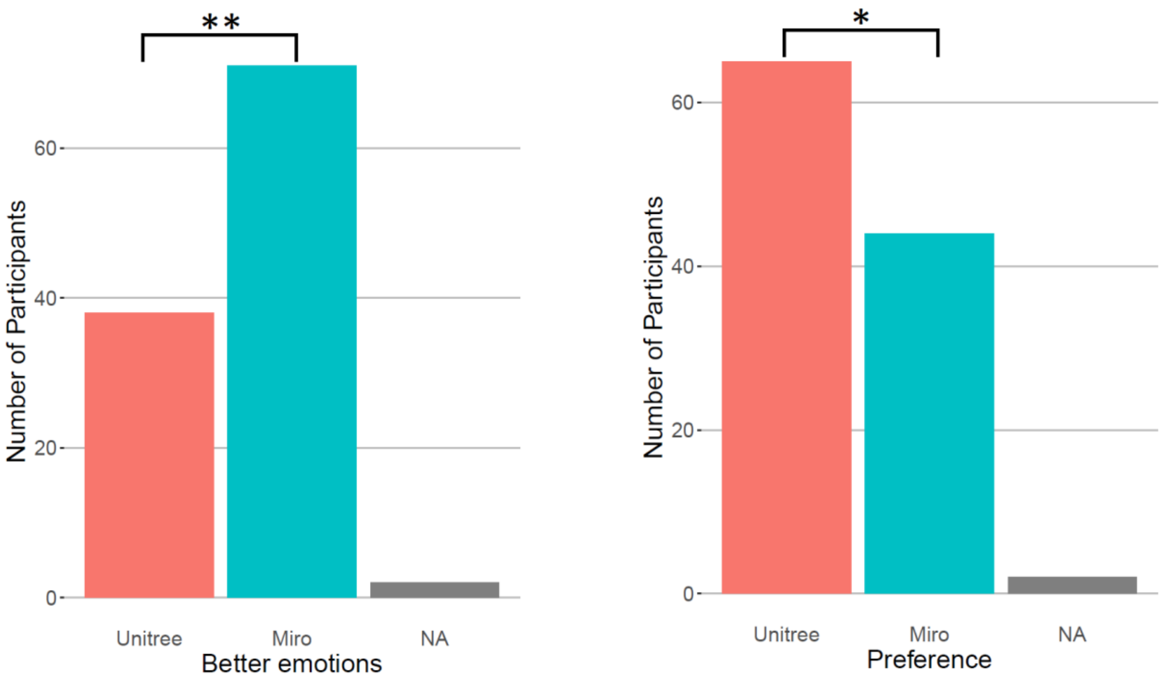

(a) (b)

Figure 8. Effects of robot embodiment: Children's responses to (a) Item 17 about which robot expressed its emotions better are presented in percentages of participants (** indicates a highly significant difference between the robots with $p < 0.01$). (b) Item 15 about which robot they preferred are presented in percentages of participants (* indicates a significant difference between the robots with $p < 0.05$).

Effects of dog-ownership

Children were also asked whether they owned pets, dogs in particular, as it was assumed that dog-ownership might have an effect on their perception of the robots.

In line with the overall effect (Figure 7(a)), our results demonstrated that children who owned dogs reportedly found Unitree easier to understand than children who did not have dogs at home ($\chi^2 = 11.329$, $df = 1$, $p < 0.001$) (Figure 9). However, there was no effect of dog-ownership in understanding Miro ($\chi^2 = 2.137$, $df = 1$, $p = 0.144$).

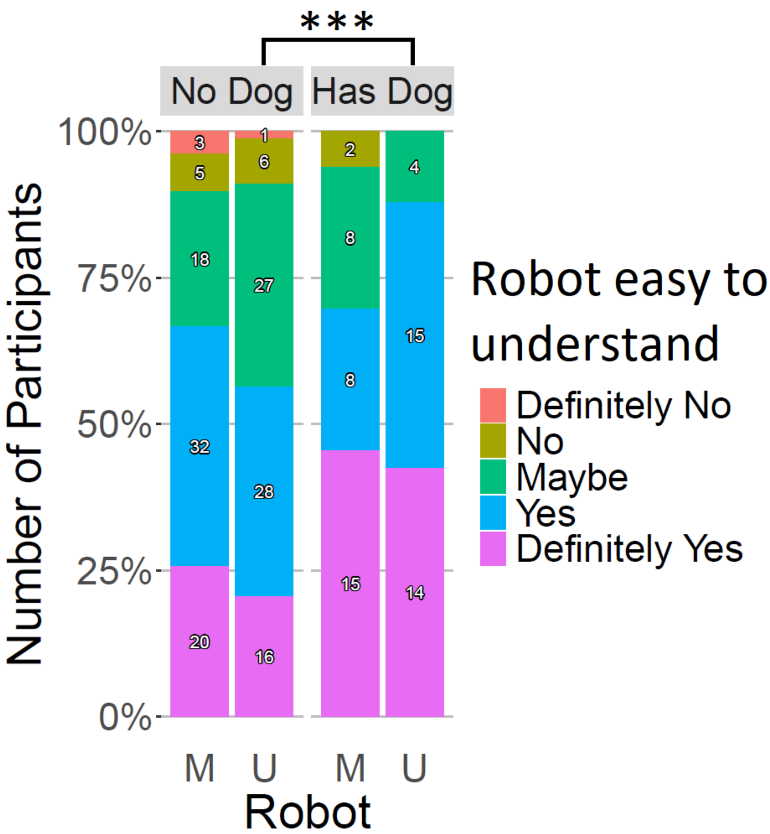

Figure 9. Effects of dog-ownership on Item 3 about how easy it was to understand each of the robots (M = Miro, U = Unitree) are presented in percentages of participants (*** indicates a highly significant difference in the category of dog ownership with the Unitree robot (U) only with $p < 0.001$).

Miro was rated significantly higher than Unitree on the questions of having own ideas ($V = 721$, $p = 0.017$) and highly significantly for having their own emotions ($V = 535.5$, $p = 0.001$) by children who do not own a dog. However, there was no significant difference in the rating of the two robots by children who own dogs (having own ideas: $V = 149$, $p = 0.092$; having own emotions: $V = 105.5$, $p = 0.675$), see Figure 10.

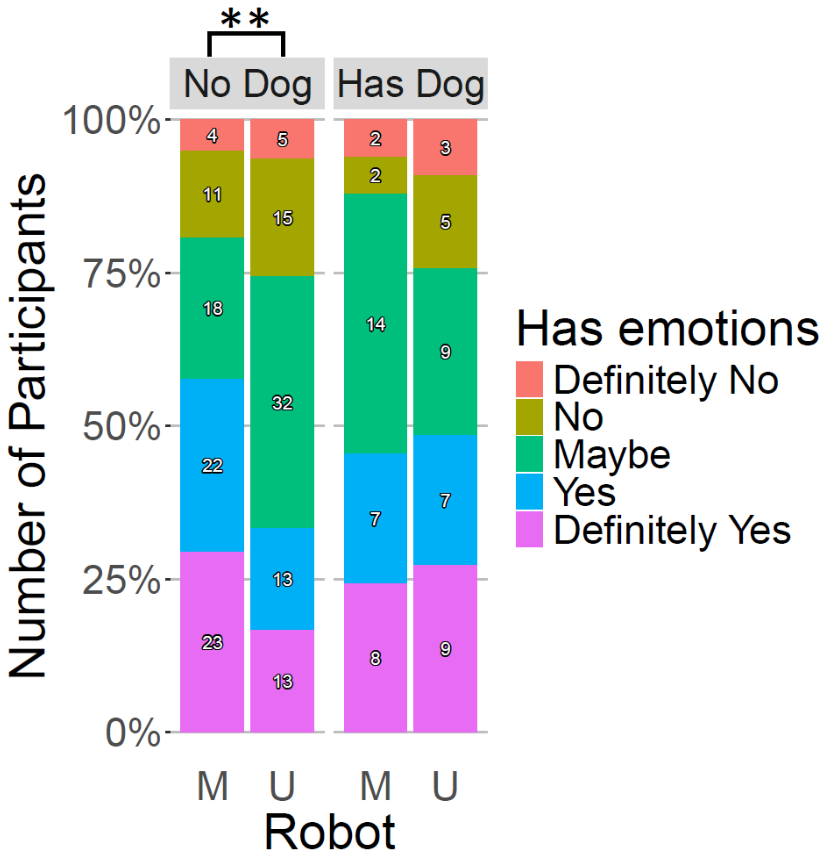

Figure 10. Effects of dog-ownership on Item 13 considering whether the robots Miro (M) or Unitree (U) have their own emotions are presented in percentages of participants (** indicates a highly significant difference between the robots with $p < 0.01$).

Unitree was rated significantly higher on the question whether the robot is alive ($\chi^2 = 6.031$, df = 1, p = 0.014) among children who have dogs at home compared to children who do not have dogs, while no significant effect of dog-ownership was found for "alive" ratings of Miro ($\chi^2 = 1.348$, df = 1, p = 0.246). Dog-ownership also meant that children wanted to have a Unitree at home significantly more than they wanted a Miro robot (V = 12, p = 0.035), while no such difference was observed among children not owning a dog (V = 463, p = 0.67). Children who owned a dog also wanted to have Unitree at home more than children who are not dog owners ($\chi^2 = 6.926$, df = 1, p = 0.008). However, dog-ownership did not have a significant effect on how much children would like to have a Miro robot at home ($\chi^2 = 0.347$, p = 0.556).

Effects of year group

There were significant differences among and within the different year groups in their view on how easy it was to understand the robots (Figure 11). Year 4 students found Miro easier to understand than Unitree (V = 181, p = 0.018), an effect that was not observable in Years 3 and 5 (Y3: V = 59.5, p = 0.074; Y5: V = 136, p = 0.962). When comparing the understanding of Unitree between year groups, an effect was found ($\chi^2 = 8.891$, df = 2, p = 0.012). In particular, Year 3 students rated it higher, finding it easier to understand than both Year 4 (W = 954, p = 0.007) and Year 5 (W = 771.5, p = 0.012) students. No such effect has been observed when comparing ratings for Miro between the year groups ($\chi^2 = 2.675$, df = 2, p = 0.263).

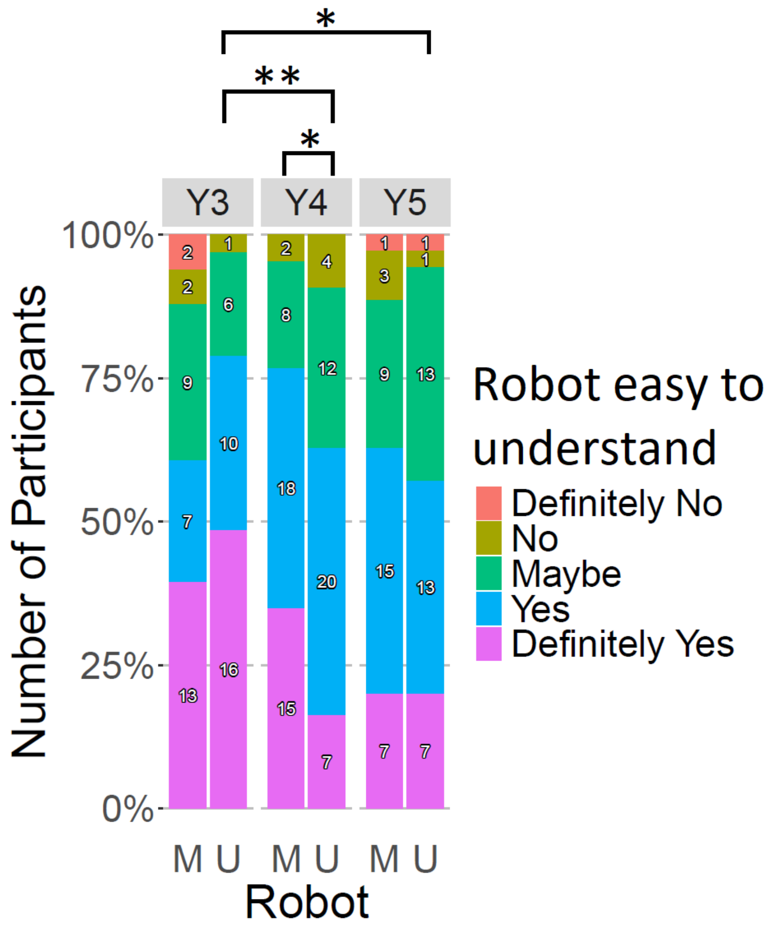

Figure 11. Effects of year group on Item 3 about how easy it was to understand the robots (M = Miro, U = Unitree) are presented in percentages of participants (* indicates differences at p < 0.05; ** indicates differences at p < 0.01).

The previously reported main effect of robot embodiment on the item of "The robot has its own ideas" (Figure 7(a)) is especially pronounced between year groups 4 and 5, with students of both groups rating

Miro higher on this item compared to Unitree (Y4: V = 222, p = 0.035; Y5: V = 151, p = 0.021). No such difference was found in Year 3 (V = 143.5, p = 0.574). When looking at the robots individually, no significant differences could be found between the year groups (Miro: χ^2 = 2.70, df = 2, p = 0.259; Unitree: χ^2 = 3.178, df = 2, p = 0.204).

Similarly, Year 4 and Year 5 students rated Miro higher on the item "The robot has its own emotions" (Figure 12) compared to Unitree (Y4: V = 145, p = 0.007; Y5: V = 150, p = 0.024). No such difference was found in Year 3 (V = 97.5, p = 0.61). No difference has been found when looking at differences between the year group ratings of the Miro robot having its own emotions (χ^2 = 3.917, df = 2, p = 0.141). However, there were significant differences among the three year-groups in their attribution of emotions to the Unitree robot (χ^2 = 8.534, df = 2, p = 0.014). Pairwise post-hoc comparisons revealed significant differences between Year 3 and Year 5 (W = 783, p = 0.009), and Year 4 and Year 5 (W = 984.5, p = 0.016), with Year 5 students rating Unitree significantly lower on this item, not attributing emotions to this robot as much as their younger peers. Comparison between Year 3 and Year 4 did not reveal significant differences in this rating (W = 760, p = 0.587).

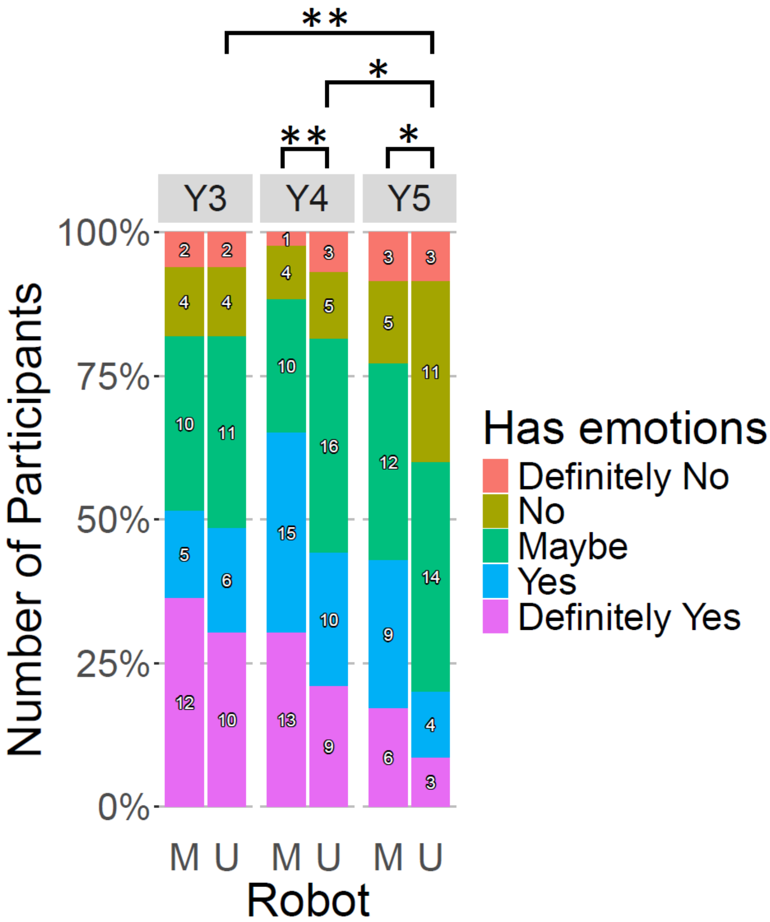

Figure 12. Effects of year group on Item 13 considering whether the robots Miro (M) and Unitree (U) have their own emotions presented in percentages of participants (* indicates differences at $p < 0.05$; ** indicates differences at $p < 0.01$).

Year 3 students significantly prefer to have a Unitree at home versus a Miro robot ($V = 26.5$, $p = 0.017$), while students of other year groups did not express a significant preference (Y4: $V = 106.5$, $p = 0.359$; Y5: $V = 91$, $p = 0.824$). Preference for Unitree was significantly different between year groups ($\chi^2 = 6.277$, $df = 2$, $p = 0.043$), i.e. Year 3 would have wanted one at home significantly more than Year 5 students ($W = 759.5$, $p = 0.016$).

Discussion

Our results supported our *Hypothesis 1a,* as Miro was rated significantly higher by children on the question of having its own emotions and it was also selected significantly more often as the robot expressing its emotions better than Unitree. The high level of successful recognition of Miro's affective behaviour is in line with earlier findings (Ghafurian et al. 2022, and in robots with similar embodiments: Lakatos et al. 2014). Even though, there was no significant difference between identifying the emotionally expressive behaviour of Miro and Unitree when getting the ball, when the ball was taken away more children recognised Miro's behaviour as sad than that of Unitree's. These findings indicate that in case of Unitree having legs and advanced locomotion capabilities, being able to jump with the front legs, and wiggle the hips up and down are effective enough to convey excitement and happiness, but in the lack of additional attachments such as ear- or tail-like features, Unitree could not express sadness as effectively as Miro.

Results also supported *Hypothesis 1b,* children very well recognised the intentions of both robots and reported that both Miro and Unitree were easy to understand, with no significant difference between the two robots. In addition, there was no significant difference considering the question which robot expressed its intentions better. Miro, however, was rated significantly higher by children on the questions of having its own ideas. These findings are in line with previous research of Koay et al. (2013) and Lakatos et al. (2014, 2016), suggesting that the dog-inspired leading behaviour can be effectively implemented on various embodiments to successfully convey intentions, creating the impression of attention and agency. For a zoomorphic robot to successfully convey a range of emotions, however, having ear and tail-like attachments seem to carry a high importance.

Results supported *Hypothesis 2,* dog-ownership did have significant effects on children's perception of the robots. Dog-ownership seemed to mean that children might have viewed Unitree more like a dog, in contrast to Miro. They found it easier to understand Unitree, perceived it significantly more alive than children who did not have a dog at home, and would have wanted a Unitree at home significantly more than they wanted a Miro. Miro, on the other hand was rated significantly higher than Unitree by children not having a dog on the questions of having own ideas and own emotions, presumably due to its more pronounced expressive behaviour. Considering that the number of children was imbalanced between these groups, and out of the 111 children participating in the analysis only 33 children had a dog, it is important to note that opinion of children not having a dog had a larger influence on the overall effects we found on robot embodiment.

Findings provided support to *Hypothesis 3* as well, year-groups also had significant effects on children's perception of the robots.

The youngest (Year 3) group seemed to be the most impressed and excited by Unitree, they rated it easier to understand than Year 4 and Year 5 students and would have wanted one at home significantly more than a Miro, and more than Year 5 students would have wanted one. Results indicated that the older the children got the less emotions they attributed to Unitree. In fact, Year 4 and Year 5 students attributed more emotions and more intentions to Miro than to Unitree.

Children also had a chance to express their opinions on the robots in an open discussion once they have taken part in both sessions and filled the questionnaires. Comments often highlighted design flaws of the robots, for instance Unitree lacking important social features such as a turnable neck and face that it could orient towards the users. It was also commonly suggested that Unitree would need a tail and (ideally floppy) ears to express emotions. Having a face capable of facial expressions to show how it feels was also mentioned by some children as a desirable feature for Unitree, while having fur was part of the recommendations from children for both robots. The noisiness of Unitree's movements was also criticised. Further comments about Unitree included: "make it more realistic and adorable", "do not have lights on it, it does not look like a dog", "make it have skin/fur in different colours", "make it personalisable (including its name)", "it should have realistic eyes with cameras in them", "it should have a mouth to catch balls", "it should be able to do tricks", "it should react to touching and stroking". In case of Miro the list of comments and recommendations by the children was a bit shorter. One comment specifically stated: "I liked Miro better because it was easier to understand, the other robot did not have a head". However, there were some criticisms and recommendations about Miro too. These included Miro not looking realistic enough, mentioning it looking like a toy vs. Unitree that looks like a robot, and being too small. It was suggested that Miro should have a mouth-like box to be able to feed it, and that it should be able to jump to express excitement. Some of the children criticised the colours of Miro's LED lights indicating its Bluetooth connection, explaining that they did not understand their meaning, while others suggested to have more bright and personalisable colours for its skin.

Interestingly, although Miro was chosen as more emotionally expressive, and received far less comments about how to potentially improve it further, Unitree was still selected to be the preferred robot significantly more often than Miro. This could presumably be due to Miro being identified as a rather toy-like robot by the children perhaps because of its small size as well as due to its restricted movements (as per their comments during the final group discussion), as well as due to Unitree being capable of a wider range of movements, providing a better play experience because of having legs. The importance of a turnable neck, head and face, ears and a tail for emotion-expression, however, was clearly recognised by the children, both via successfully identifying emotions expressed by Miro, and by commenting on the lack of such features in case of Unitree.

To answer the initial question of the paper whether a "robot dog" need legs, ears, and tail, based on the overall findings of the paper we can conclude that while only legs were enough for children to attribute emotions and intentions to Unitree, and no legs but a face, ears, and a tail were enough for the children to attribute emotions and intentions to Miro, having all these features together on a zoomorphic robot would probably result in an even higher level of understanding of the robot's behaviour as well as higher levels of emotion- and intention attribution - assuming that features of the embodiment are used in a biologically evidenced, credible way.

It is important to recognise that even though there were differences in the perception of the two robots, both Miro and Unitree were very well understood by the children, and they both successfully conveyed the intended emotions and intentions. This provides further evidence for the applicability of the ethorobotics approach (Miklósi and Abdai 2024) and emphasizes the importance of acceptable and credible behavioural design for social robots that matches their function and embodiment. Embodiment can have a strong effect on users' initial expectations of a robot and depending on how well a robot's function and behaviour matches those expectations it also influences robot acceptability. Zoomorphic embodiment has been suggested to moderate user expectations towards the capabilities of a robot, and to create a less threatening, and hence more acceptable interaction through the addition of design elements that can be used to convey affective states, such as ears and tail (Barber et al. 2021; Korcsok et al. 2024). Findings of the current study provided further evidence to this statement.

On the other hand, it was suggested that dog-like features that have a close resemblance to dogs - instead of a rather simplistic zoomorphic design – could raise unrealistic user expectations towards the capabilities of a robot (Schellin et al. 2020), comparing it to real dogs. This could create a discrepancy between the embodiment and the behaviour (Uncanny Valley effect (Zhang et al. 2020)), leading to decreased user satisfaction and acceptability of the robot. Previous research of Fujita (2004) involving the AIBO robot also suggested to limit the robot's resemblance to real dogs in order to calibrate user expectations towards the capabilities of the robot and avoid raising unrealistic expectations.

Miro was clearly designed with this in mind, not resembling any animal species too closely but rather looking like a cross between a dog, a rabbit and a donkey, while conveying a high level of animacy in its behaviour and affective features. On the other hand, Unitree was not inherently designed with HRI in mind, but rather to prioritise dynamic mobility and to provide as a research and educational platform to facilitate learning about robotics and engineering principles. Other similar quadruped robots with such advanced locomotion capabilities are typically designed for tasks involving difficult terrain or dangerous situations, e.g., search and rescue situations or construction sites (Korcsok et al. 2024). The next iteration of Unitree (Go2), however, already has been developed to be capable of more dog-like social interactions, such as giving a paw and doing tricks. Even though this new version still lacks a turnable head, and other expressive zoomorphic design elements (e.g., ears, tail), its improved abilities make it already better suited for HRI than the Unitree version used in this study. And while Unitree was not originally designed for HRI, the current study demonstrated that the implementation of simple biologically inspired interactive behaviours could achieve acceptable and credible social interactions, opening the possibilities of other potential future applications in social (and potentially educational and assistive) robotics as well. Future research could explore ways to incorporate additional social signals to realise expressive features (Holthaus et al. 2023) into Unitree Go robots to balance their physical and social capabilities, and to allow the robots to simulate behaviours that are not only engaging but also responsive, bridging the gap between the expressive limitations of earlier robots like Paro and the dynamic capabilities of modern quadrupeds, thereby expanding their potential applications in educational and therapeutic contexts. This could further include using multimodal signals, considering the acoustic as well as the visual modality, leading to more complex and efficient expressive behaviours (Gácsi et al. 2016), and to closer replicating the richness of real pet behaviours for long-term user engagement. However, long-term user engagement can only be realistically tested in long-term studies, hence future research could further focus on placing these robots in real world environments, e.g., schools, care homes or in people's homes for long periods of time.

Limitations of the study

Due to the setup with the school and the experiment being done in real-world settings instead of laboratory conditions, it was not possible to keep the children from talking between themselves in recess and/or lunch break, so there was possibly information canvassed between children about the robots (Miro/Unitree). Another limitation concerned the constraint that we had in the school regarding the division of the students in each year group, which meant that a 50-50 split between the conditions was not possible. Instead, 2/3 of the children saw the interaction with Unitree first while the rest saw Miro first. A further limitation involved the unbalanced participant numbers regarding dog-ownership, which – considering that dog-ownership had significant effects on children's perception of the robots – influenced the main effects of robot embodiment identified in the study. The experimental design carried an additional limitation, namely that the children could use the behaviour of the Experimenter as a way to understand the intention of the robot. In the future it might be interesting to analyse how well the displayed emotions are recognised if the robots can also express incongruent emotions (e.g., sadness or fear when getting the ball), or if the situation itself is ambiguous e.g., the robot receives a different object than what it signalled for.

Conclusions for future biology

Biology often provides inspiration and models for new technological developments, as it happens in the development of zoomorphic robots as well, providing models for both physical and behavioural attributes of the technology. On the other hand, many of recent developments in biology have been driven by technological advancements. This two-way relationship between different areas of biology and technology often resulted in the emergence of new interdisciplinary fields, including synthetic biology, neurogenetics, bioinformatics, and systems biology among others. In fact, interdisciplinarity has been gaining more and more significance in research in recent years, taking new integrative approaches to create novel solutions to various research problems. One such recently emerged interdisciplinary field is the field of Ethorobotics, which combines the disciplines of ethology, robotics engineering, and HRI research to develop socially acceptable and credible robotic devices suitable for long-term user engagement. This relatively novel interdisciplinary research field of Ethorobotics is expected to play a significant role in advancing robotics through the 5th industrial revolution, which puts humans, and the interaction of humans and technology in its centre (Korcsok, 2023).

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