University of Southern Denmark

A Soft Social Robot to Alleviate Anxiety Symptoms in Children

Klausen, Troels Aske; Vlachos, Evgenios; Jørgensen, Jonas

Published in:
Social Robotics

DOI:
10.1007/978-981-96-3522-1_12

Publication date:
2025

Document version:
Accepted manuscript

Document license:
Unspecified

Citation for pulished version (APA):
Klausen, T. A., Vlachos, E., & Jørgensen, J. (2025). A Soft Social Robot to Alleviate Anxiety Symptoms in Children. In O. Palinko, L. Bodenhagen, J.-J. Cabibihan, K. Fischer, S. Šabanović, K. Winkle, L. Behera, S. S. Ge, D. Chrysostomou, W. Jiang, & H. He (Eds.), *Social Robotics: 16th International Conference, ICSR + AI 2024, Odense, Denmark, October 23–26, 2024, Proceedings* (pp. 121-134). Springer.
https://doi.org/10.1007/978-981-96-3522-1_12

Go to publication entry in University of Southern Denmark's Research Portal

Terms of use
This work is brought to you by the University of Southern Denmark.
Unless otherwise specified it has been shared according to the terms for self-archiving.
If no other license is stated, these terms apply:

- You may download this work for personal use only.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying this open access version

If you believe that this document breaches copyright please contact us providing details and we will investigate your claim.
Please direct all enquiries to puresupport@bib.sdu.dk

Download date: 27. Apr. 2025

A Soft Social Robot to Alleviate Anxiety Symptoms in Children

Troels Aske Klausen[1[0000−0002−2803−5323]], Evgenios Vlachos[2,3[0000−0001−8235−0423]], and Jonas Jørgensen[4[0000−0001−9598−3414]]

[1] Faculty of Engineering, University of Southern Denmark, Denmark
[2] The Mærsk Mc-Kinney Møller Institute, University of Southern Denmark, Denmark
[3] University Library of Southern Denmark, University of Southern Denmark, Denmark; evl@bib.sdu.dk
[4] SDU Soft Robotics, SDU Biorobotics, The Mærsk Mc-Kinney Møller Institute, University of Southern Denmark, Denmark; jonj@mmmi.sdu.dk

Abstract. We present the design and development of a novel sea-creature-like soft social robot, Breco, intended for therapeutic interventions to alleviate anxiety symptoms in children. When hugged, the robot uses slow breath-like expansive movements on its chest and stomach region as a means to comfort and calm the child. The robot was manufactured from soft silicone and uses pneumatic actuation. It features actuated ears, lights, a pressure sensor, and an inertial measurement unit to also enable play-based interaction. The prototype was pilot tested with a group of three healthy children 5-6 years of age to investigate how the children assessed the robot's design and features in relation to its function as an intervention tool. Results showed that the children perceived the robot as friendly and would like to interact with it physically indicating that the robot's design and behavior matched the intended interaction.

Keywords: robot design and development · robots for children · companion robots · soft robotics · anxiety · human-robot interaction

1 Introduction

Anxiety is one of the most common mental health disorders, which affects roughly one third of the population. Children constitute a portion of the diagnosed population, and may experience social anxiety due to challenges such as difficulty in meeting new people, worry of being negatively assessed in social situations, or difficulty in being the center of attention [1]. The early onset of social anxiety in children may be linked to their social understanding and their ability to express emotions in social circumstances, and might have significant detrimental effects on their social and emotional development [2]. Thus, early identification and intervention is especially important [3]. State anxiety in children also occurs during medical check-ups, such as venipuncture, where 83% of children aged 2.5-6 years old, 51% of children aged 7-12 years old, and 28% of adolescents experience high levels of anxiety[4].

Robots can offer non-judgemental companionship, which can create a safe space to express emotions [5] as they are easily accessible and available at any time. Thus they have potential to function as accessible tools for helping children to cope with emotional distress and anxiety. Notable examples of this include the robot companion "Buddy" aiming to relieve separation anxiety of children and parents by having children turn to it when feeling anxious [6], the Huggable robot designed to provide users with a sense of social presence and companionship through touch and physical interaction [7], the TACO robot designed as a therapeutic active companion robot to alleviate anxiety in hospitalized children [8], the roboRETMAN robot designed to use cognitive reappraisal statements to help regulate children's mood [9], the Paro robot designed to provide social and emotional support to those with cognitive or emotional disabilities [10], the Purrble robot designed to offer in-the-moment emotion regulation for children [11], and the Emobie social robot designed to provide companionship and comfort to children with anxiety [12]. Apart from robots, other proposed technologies to alleviate anxiety symptoms include a tactile aid in the form of a huggable breathing soft cushion for easing state anxiety in students during anticipation of a test[13], and the small wearable Doppel, which works through gentle heartbeat-like stimulation of the wrist, providing a calming effect lowering anxiety of people preparing for or performing a public speech[14]. The topic of alleviating anxiety specifically for children by means of social robots, however, is still at an early stage and remains under-explored in research.

Most robots intended for nonverbal Human-Robot Interaction (HRI) are specifically engineered to communicate nonverbally through facial expressions, body movements, and gaze [15]. However, researchers are broadening the area of nonverbal HRI, and other niche communication modalities are increasingly being investigated. One of these is using breathing as a means of expression and interaction. In [16], the researchers developed the Haptic Creature robot to investigate affective touch in social situations. This robot features a breathing mechanism designed to bring a living and relaxing quality to the robot. The researchers found that stroking the robot when it was breathing produced an emotional change and reduction in anxiety[16]. Similarly, another study found that touching a soft breathing robot caused the participants to breathe deeper, more regularly and to have brain wave changes indicating increased positive emotional valence [17].

Unlike traditional machines and robots, soft robots are characterized by their minimal or complete absence of rigid components. Instead, they primarily consist of fluids, gels, soft polymers, and other materials with high deformability and flexibility. Soft robots can be defined as systems that are capable of autonomous behavior and primarily composed of materials with moduli in the range of soft biological materials [18]. As soft robots are made of materials that match the compliance of biological matter, their design and functionalities are often biologically inspired. Soft robots show great potential in the field of physical HRI, as they enable biomechanically compliant interaction[19] with skin safe materials. Thus, a benefit of using silicone-based soft robots in interactions with children is their soft feel and their gentle movements that may be beneficial for eliciting trust and social bonding [20] to sustain use. In addition, soft silicone robots offer better hygiene, than, e.g., fur-covered ones, as the silicone material can easily be cleaned and disinfected.

In this paper, we present a novel sea-creature-like soft robot called *Breco* (short for breathing companion), designed to alleviate anxiety symptoms in children 5-6 years of age, e.g., during challenging social circumstances associated with transitioning to the school system. The robot uses emulated breathing to calm the child through haptic interaction. The design is based on prior work on tactile interaction and the principle of entrainment, which describes how rhythmic biological signals can synchronize to the frequency of an external stimulus. This principle has previously been shown to apply to technologies that use tactile stimuli to help regulate emotions [21, 22]. We hypothesize that the slow respiratory rate of the robot may entrain the respiratory rate of the child resulting in slower breathing. As deep breathing (slow diaphragmatic breathing) has been shown to reduce anxiety [23] this could help alleviate anxiety symptoms. A user study follows, which aims to investigate children's assessment of the Breco robot's visual design, features, and potential for use in interventions aimed at relieving anxiety. Findings from the pilot user study are analyzed, and, finally, the entirety of the research is discussed, including limitations and future work.

2 Design

2.1 Designing robots for children

Child-robot interaction (CRI) is a growing sub-field of HRI research. Understanding that a child's continuous physical and neurophysical development creates distinct needs in relation to robot use is essential. Both the robot design and interaction capabilities must be taken into account. Different designs of robots have been proven to work well for CRI, including humanoid robots ([24],[25],[26]); zoomorphic robots ([27],[28],[7],[11]), and abstractly shaped robots [29]. The interaction schemes for the different robot types were different, with a tendency for children to interact more physically with the zoomorphic robots as these -in most cases- did not use verbal communication. Anthropomorphic robots were mainly used as a facilitator to a doctor/nurse or as a distraction during a medical procedure, meaning that the robot was just placed in front of the child without the robot being designed or programmed to be more inviting to physical interaction. Therefore, the visual design of our novel robot should invite children to seek physical contact and comfort in the robot.

Apart from the appearance and design, the play capabilities of a robot are also important as children learn and develop through play and social interaction. Therefore, it can be beneficial that CRI is also engaging, play-based, and modeled on social interaction[30]. As an example, the interactive robot Keepon designed for children with autism uses attentive actions to keep eye contact with children in addition to emotive actions to express, e.g., pleasure and excitement [31]. Another example is the robot Cubetto, a mobile floor robot shaped like a wooden box that helps children learn coding and computational thinking through hands-on play with small physical coding blocks placed on a control panel [32]. In order to create bonding through play the robot should encompass toy features.

Another critical element of designing robots for children is the child's safety. Children tend to explore the usage of robots through imaginary play, which can subject the robots to unintended treatment. Unintended usages may thus not pose a risk of harm to the child. A rule of thumb for designing robots for children is that there should be no right, or wrong way to interact with the robot. Prior work have used compliant soft materials for the outer layer of a robot to ensure safe interaction with the child ([29],[33]), thus our robot should be soft, relatively small in size so it can be handled by children and with the ability to be used in an everyday setting.

A person observing someone else experiencing an emotional state, that is known to the observer, induces the same neurological effect in the brain of the observer activating the same brain areas that correspond to the same affective states being experienced and observed, this is known as the "Shared Network Hypothesis" [34]. These findings of shared neural representations have been reported in test subjects experiencing different types of feelings, emotions and emotional states, such as: fear and anger [35], disgust [36], pain [37], but also the physical effect of breathlessness by observing breath-holding in another individual [38]. Breathing is more than just a regular rhythm like the heart's beating, it is linked to the individual's emotional state and mental health. A prior study confirmed that unpleasant emotions would alter the breathing pattern of the participants [39]. Another study has observed an increase in the respiratory rate of participants during anxiety anticipation [40]. Various types of breaths serve different purposes (e.g., sleeping, excited, regular, gasping, yawning, and sighing). Two recent studies showed that a soft robot could effectively convey distinct emotional states, such as arousal and pleasure, to human users by simulating diaphragmatic breathing, in which air is directed to the belly, at varying frequencies ([41],[42]).

When designing robots for children, ethical considerations also need to be made. Due to a child's immature cognitive development, they may not see a robot as a computer-controlled mechanical device but instead, anthropomorphize the robot and its features based on their imagination and fantasies [43]. Hence, they might not fully understand that a robot is a machine. This could cause concern for children to be deceived by the robot's capabilities. Another concern is related to the relationship between the child and the robot. Over an extended time of use a strong emotional attachment can occur, and a technical malfunction, or breakdown of the robot could be hard on the child [44]. Lastly, our robot should have an integrated design, and be lightweight.

2.2 Design inspirations

Based on prior research on breathing robots mentioned above, the idea was born to create a small portable zoomorphic robot, with inflatable chambers inside its chest and stomach region enabling children to feel the robot's breathing when hugging it.

Various sources including toy animals, cartoon characters, and AI-generated images served as inspirations for developing the robot's design. Fictional characters and designs portrayed as having a comforting effect on children through haptic interaction were prioritized. A major inspiration was the character "Blue" of the Netflix animated film "The Sea Beast" [5]. "Blue" is a gelatinous monster who befriends a small girl. Their nonverbal interaction encompasses gestures and facial expressions and soothing through caresses and hugs. Text-to-image generative AI was also used to explore other possibilities for the design. The "Cute Creature Generator API"[6] provided by DeepAI was queried with the search string: "Soft robot for children, friendly, zoomorphic, anthropomorphic, nonverbal communication". In general, the generated outputs consisted of small furry creatures with eyes, noses, ears, and limbs. Common features include rounded overall shapes, big colorful eyes, and diminutive legs. Figure 1 shows a selection of the generated creatures.

Fig. 1. AI generated soft creatures for inspiration.

2.3 Practical requirements, use constraints and robot morphology

Practical constraints on the design were derived from the robot's intended use and user group. The size of the robot should not be larger than what a child can easily carry and handle or hug. A five-year-old child's anthropomorphic standard arm span is 107 cm [45]. The Paro robot, which is used in a similar fashion for hugging by adults, has a length of 57 cm and a width of 35 cm[7]. These measurements were halved as a reference for a robot that might fit a child, ending up with an ideal length of roughly 30 cm and a width of 18 cm. It was then decided that the robot should be able to stand straight on its own, for ease of use and easy storage in a domestic setting. To ensure that the robot's breathing is detectable, the robot should have a wide chest region and legs that

[5] The Sea Beast, https://www.imdb.com/title/tt9288046/ (accessed June 2nd, 2024)
[6] DeepAI - Cute Creature Generator API, https://deepai.org/machine-learning-model/cute-creature-generator (accessed June 2nd, 2024)
[7] PARO Therapeutic Robot, www.parorobots.com (accessed June 2nd, 2024)

are angled outwards for unhindered hugging. Lastly, the color of the robot should be associated with positive and relaxing content, thus blue was chosen [46].

Taking into consideration the specified requirements, and the inspirations mentioned earlier, a series of hand drawings were executed to brainstorm ideas for the robot design. Three candidate robot designs were executed as CAD models and reviewed and discussed by the researchers and another researcher formally trained as a digital designer. The design shown in Fig. 2 was chosen. Considerations on child-safety and further discussion led to a series of iterations of the design being, wherein the head was made smaller and moved downwards, the neck was altered to have a less abrupt transition to the torso, and the legs were enlarged and moved further back on the body (Fig. 2 (right)).

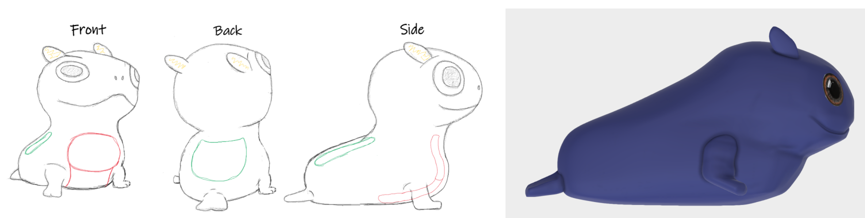

Fig. 2. Left: Initial sketch of the Breco robot design. Right: CAD rendering of the final Breco robot design.

3 Implementation, actuation, and sensing

To allow for accurate replication of breath-like motions, the robot design features two inflatable chambers at the chest and stomach region. These may be actuated individually to replicate the asynchronous movement of the chest and the stomach observable when humans and mammals breathe. The placement of the chambers allows the child to feel the expansive movement when hugging the robot. A pump and valve used for actuation was placed inside the robot with tubes for air inlet and outlet running through the its nostrils. The implementation used for the pilot study, did not feature asynchronous two-part breathing due to inability to fit in a separate pump and valve for actuating the stomach chamber. The robot's breathing rate was set to 9.2 breaths per minute based on prior work [41]. Actuation was added to the ears by using servo motors as well as LED lights, to provide expressive means for increasing the robot's liveliness and responsiveness to enable play-based interaction with it as well.

To detect the child hugging or stroking the robot, a pressure sensor was connected to a small air compartment on the back of the robot. An inertial measurement unit (IMU) was implemented to infer the body orientation of the robot. The control code used centers on the robot's body orientation with three modes defined by the orientation: *Idle mode*, *Relief mode*, and *Scared mode*. When placed flat on its belly the robot enters Idle mode and the LEDs pulsate at its' breathing rate. If the pressure sensor on the back of the robot detects compression during Idle mode, the robot wiggles its ears from the inward position to the outward position two times in the course of six seconds. When held in an upright position the robot enters Relief mode, the LEDs turn off, and the robot waits to be hugged to initiate the breathing cycle. When held upside down the robot enters Scared mode where the LEDs blink fast (2.5Hz).

Figure 2 (left) shows the placement of the main elements of the robot. The red section indicates the placement of the chest and stomach chambers actuated to emulate breathing. The green section indicates the placement of the pressure sensor used for detection of hugs and strokes. The yellow section indicates the actuated ears. The robot morphology consists of an interior skeleton encasing all electronic and electrical components and an outer silicone shell. The skeleton, interior parts, and the molds used to cast the silicone shell were designed in a CAD program and manufactured by 3D printing and laser cutting. The silicone shell was cast from Ecoflex 0050 silicone dyed with Silc Pig-Blue (PMS 2757C) using a multi-step casting process with several outer and inner mold parts used. The technical design and the fabrication of the robot is described in detail in the supplementary materials (Sect. 5), which also contain a parts list. The robot was manually assembled and wired, with all control software written in the Arduino IDE. The physical robot is shown in Figure 3, and Table 1 lists its specifications. A demonstration video of the robot is available online [8].

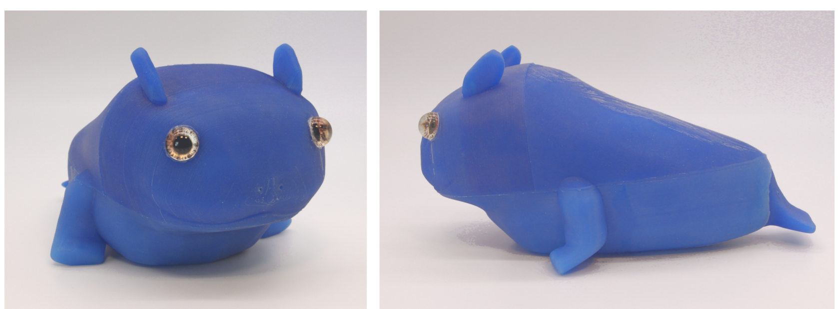

Fig. 3. The Breco robot.

4 Evaluation

A pilot user study was conducted at a kindergarten in Odense, Denmark that is part of the municipality program called "Verdens Bedste Robotby"(The World's

[8] Demonstration video: https://www.youtube.com/watch?v=1eL$_v6F7F$78

Length	295 mm	**Max. chest expansion**	15 mm
Height	148 mm	**Inflation time (to max.)**	2000 ms
Width	200 mm	**Deflation time (from max.)**	4500 ms
Weight	2070 g	**Ears range of motion**	8 mm

Table 1. Robot specifications.

best robot city)[9], where robots are introduced to children at an early age. Before conducting the user study we visited the kindergarten without the robot to greet the children and learn more about the kindergarten's environment and their use of robots. The pilot study itself consisted of two sessions at the kindergarten with a two weeks interval.

Children were recruited for the pilot user study by sending information about the project and a consent form to parents of children aged 5-6 years old via the Aula platform [10]. All in all, three children participated in the study. Two children of the same age were present at both sessions, a girl (Child1 hereafter) and a boy (Child2 hereafter), while the last child - who was a boy and one year older - was only present at the second session (Child3 hereafter). A semi-structured interview format was chosen for collecting data, as it allows for deviating from pre-planned questions based on the children's responses. In the first session, the main researcher would introduce themselves and the robot to the children. The features of the robot were presented and the children were given the opportunity to hold, hug, and interact with the robot as they preferred. Questions planned for the first session revolved around the children's first impression of the robot and what they thought the robot's responses and behavior meant, including: *"Where do you think the robot lives?"*; *"What does the robot remind you of?"*; *"What do you think it means when the robot moves its ears?"*; *"What do you think it means when the robot blinks fast?"*; *"Why do you think the robot has pulsating light behind its ears?"*.

For the second session, each child was brought to the room individually and was asked what they remembered about the robot from the first session. Following this, the breathing mechanism was re-introduced and a thought scenario was set up with the researcher asking questions in regards to how the children could imagine using the robot. Children of that young age can neither fully understand what anxiety is nor communicate their feelings adequately, thus the scenarios presented revolved around familiar emotions like them being sad or scared as a proxy of the discomfort experienced during anxiety.

Both sessions were conducted in a room familiar to the children. Bean bags were placed for the children to sit on, and the researcher would sit on the floor in front of them. Both sessions were video recorded with a camera placed at an angle

[9] Verdens bedste robotby, https://www.odense.dk/verdensbedsterobotbyiboernehoejde (accessed June 2nd, 2024)

[10] Aula is Denmark's secure digital platform for communication between the kindergarten and the parents, https://aulainfo.dk/wp-content/uploads/Aula-foraeldrefolder-Engelsk-DAG-juni-2020.pdf (accessed June 2nd, 2024)

behind the researcher to capture the facial expressions and physical responses of the children. The children were brought to the room by their pedagogue and the sessions ended when they got uninterested to participate further. The pedagogue stayed in the room during the sessions to make sure the children never felt discomfort. Figure 4 shows instances from the sessions.

Fig. 4. Children interacting with the robot: activation of the ear mechanism (left); lying with the robot (top right); and playing with the robot's tail (bottom right).

4.1 Results

Thematic analysis [47] was conducted using transcripts of the children's interaction with the robot. Below we report on five themes that were constructed based on inductive coding of the data taking into account the interview questions posed and the aim of the pilot study.

The robot's visual design The children perceived the robot's visual design as indicating friendliness, stating that the robot was cute and that they wanted to be friends with it. The robot was perceived as zoomorphic and was compared to sea animals: *"It looks a bit like a whale [...] it has the same shape, a bit like [...] because it also has a fin like this [...] and then it has the same back."* (Child1); *"It looks like a fish."* (Child3). Despite this, all children acknowledged the robot as being a machine: *"In a box [...] it's just because it [the robot] gets more power* *if there are wires in [the box]."* (Child1) when asked where the robot lives; *"Can you also build a new [robot] for me today?"* (Child2); *"How do you make these robots?"* (Child3).

Physical interaction with the robot All children interacted physically with the robot by touching it, holding it, hugging it, caressing it, and playing with its arms, ears, and tail. In the first session, during the researcher's presentation of the robot, both Child1 and Child2 seemed eager to interact physically with the robot, as they both asked if they could hold it. The softness of the tail, arms, and ears seemed to invite haptic interaction, with these being squeezed and played with by all three children multiple times. In addition, the children investigated the soft body and features of the robot by actively touching it.

The robot's features The fast blinking of the LED lights was perceived differently by the individual children, and also contravening perceptions between sessions were seen. In session 1, both Child1 and Child2 perceived the fast blinking as a trait of happiness, but in session 2, Child1 said the fast blinking meant the robot was tired of being held upside down. A similar observation was made for the ears of the robot, with Child3 being the only one perceiving the ear movements as an indication of sadness. The children also mimicked the features of the robot, with Child1 and Child2 both blowing up their chest and holding their breath when the researcher showed the robot's breathing mechanism.

A robot companion providing comfort As a part of the semi-structured interview, the children were presented with scenarios involving them being sad or scared. The children were asked if they would like to have the robot on these occasions and if so, how they would use it: *"Just like my teddy bear, you could hug it to make you happy again."* (Child1);*"Hug it [...] so that I would be happy again"* (Child3). Child2 responded that he would like to have the robot if he felt sad, but did not state how he would interact with it. However, during Session 1, Child2 hugged the robot multiple times, stating it felt nice. Child2 also lay in the bean bag with the robot on his chest and slowly caressed the robot while talking to the researcher (Figure 4).

Ease of use The children had difficulty handling the robot at arm's length, but increasingly gained control during the sessions when holding it closer to their bodies. Child1 also dropped the robot once when trying to hold it upside down. When asked, all children stated that the robot was not too heavy for them. This response could be based on the fact that the children wanted to appear to be strong, and Child3 confirmed that he felt strong when asked if that was the reason why the robot felt lighter to him. However, Child1 did mention in the second session, without being asked, that the robot was very heavy when the robot was placed on her lap. On multiple occasions, the children needed the researcher's help starting the breathing mechanism when hugging the robot. The breathing mechanism did not start due to the robot's orientation, e.g., when lying down, and also due to the pressure sensor's placement not aligning with how the children hugged the robot. This caused the children to hug the robot with increasing force, as they did not understand why the robot would not start breathing.

5 Discussion

The results of the pilot study support that the children perceived the Breco robot as friendly and would like to interact with it physically through hugs and touch. Even if the pilot user study did not include children experiencing anxiety, the findings may be taken as an indication that the robot's design and programming matched well the intended use and desired interaction between children and robot.

Although the current Breco design shows promise, further improvements are obtainable. The size of the current hardware inside the robot limits its functionalities, thus further scaling down the size of the components (i.e., pumps, valves, battery) is required. By scaling down the internal components, a smaller and lighter design could be achieved, increasing its ease of use for children. Further iterations of the software could allow for a more interactive robot, which is more responsive to how the children handle and orient it. Additionally, a stronger servo motor for the ear mechanism is needed to increase the range of movement and make their movements more visible, which could augment the robot's expressivity and life-likeness.

The fact that the study took place in a familiar place to the children (their kindergarten) with children familiar with robots may have influenced the children's perception towards robots in general, decreased the novelty effect of meeting the robot, and may not accurately reflect situations where children experience significant anxiety. With just three children participating in the user study, only limited insight into the robot's usage was obtained. In order to understand how the robot is perceived in general, studies with larger population sizes and more realistic settings are needed. Furthermore, this future work needs to validate the robot's potential for relieving anxiety symptoms in children in comparisons with other methods for anxiety relief.

Supplementary materials

A detailed technical description of the robot's design and fabrication, as well as project information used for the kindergarten visits including the consent form are available online at: `https://doi.org/10.5281/zenodo.12635174`

References

1. Rasouli, S. e. a. Potential Applications of Social Robots in Robot-Assisted Interventions for Social Anxiety. *International Journal of Social Robotics* **14.** Springer Science and Business Media B.V., 1–32 (2022).
2. Colonnesi, C. e. a. Social anxiety symptoms in young children: Investigating the interplay of theory of mind and expressions of shyness. *Journal of abnormal child psychology* **45,** 997–1011 (2017).
3. Edwards, S. L., Rapee, R. M., Kennedy, S. J. & Spence, S. H. The assessment of anxiety symptoms in preschool-aged children: the revised Preschool Anxiety Scale. *J. of Clin. Child & Adolesc. Psychology* **39,** 400–409 (2010).
4. Humphrey, G. B., Boon, C. M., van Linden van den Heuvell, G. F. & van de Wiel, H. B. The occurrence of high levels of acute behavioral distress in children and adolescents undergoing routine venipunctures. eng. *Pediatrics* **90,** 87–91. ISSN: 0031-4005 (July 1992).
5. Axelsson, M., Spitale, M. & Gunes, H. Robots as Mental Well-being Coaches: Design and Ethical Recommendations. *J. Hum.-Robot Interact.* **13,** 19:1–19:55 (June 2024).
6. Qian, Y., Chang, D. & Sun, Y. *BUDDY: A Companion Product Design for Alleviating Parent-Child Separation Anxiety* in *IEEE Int. Conf. Comput. Support. Coop. Work Des., CSCWD* (IEEE, 2022), 221–226.
7. Jeong, S. *et al. Designing a socially assistive robot for pediatric care* in *Proceedings of the 14th international conference on interaction design and children* (2015), 387–390.
8. O'Brien, C., O'Mara, M., Issartel, J. & McGinn, C. *Exploring the design space of therapeutic robot companions for children* in *Proceedings of the 2021 ACM/IEEE International Conference on Human-Robot Interaction* (2021), 243–251.
9. David, O. A. & David, D. How can we best use technology to teach children to regulate emotions? efficacy of the cognitive reappraisal strategy based on robot versus cartoons versus written statements in regulating test anxiety. *J. of Rational-Emotive & Cognitive-Behavior Therapy* **40,** 793–802 (2022).
10. Kitt, E. R., Crossman, M. K., Matijczak, A., Burns, G. B. & Kazdin, A. E. Evaluating the role of a socially assistive robot in children's mental health care. *Journal of child and family studies* **30,** 1722–1735 (2021).
11. Daudén Roquet, C. *et al. Exploring situated & embodied support for youth's mental health: design opportunities for interactive tangible device* in *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (2022), 1–16.
12. Arnold, L. *Emobie™: A robot companion for children with anxiety* in *2016 11th ACM/IEEE International Conference on Human-Robot Interaction (HRI)* (2016), 413–414.
13. Haynes, A. C. *et al.* A calming hug: Design and validation of a tactile aid to ease anxiety. en. *PLOS ONE* **17,** e0259838. ISSN: 1932-6203 (Mar. 2022).
14. Azevedo, R. *et al.* The calming effect of a new wearable device during the anticipation of public speech. *Scientific Reports* **7.** Nature (2017).

15. Saunderson, S. & Nejat, G. How Robots Influence Humans: A Survey of Nonverbal Communication in Social Human–Robot Interaction. *International Journal of Social Robotics* **11.** Publisher: Springer Science and Business Media B.V., 575–608 (2019).
16. Sefidgar, Y. *et al.* Design and Evaluation of a Touch-Centered Calming Interaction with a Social Robot. *IEEE Transactions on Affective Computing* **7.** IEEE, 108–121 (2016).
17. Asadi, A., Niebuhr, O., Jorgensen, J. & Fischer, K. *Inducing Changes in Breathing Patterns Using a Soft Robot* in *ACM/IEEE Int. Conf. Hum.-Rob. Interact.* **2022-March** (IEEE Computer Society, 2022), 683–687.
18. Rus, D. & Tolley, M. T. Design, fabrication and control of soft robots. *Nature* **521.** Type: Journal Article, 467–475 (2015).
19. Majidi, C. Soft Robotics: A Perspective - Current Trends and Prospects for the Future. *Soft Robotics* **1.** Mary Ann Liebert Inc., 5–11 (2014).
20. Arnold, T. & Scheutz, M. The tactile ethics of soft robotics: Designing wisely for human-robot interaction. *Soft Robotics* **4.** Mary Ann Liebert Inc., 81–87 (2017).
21. Choi, K. Y. & Ishii, H. *ambienBeat: Wrist-worn Mobile Tactile Biofeedback for Heart Rate Rhythmic Regulation* in *Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction* (ACM, Feb. 2020), 17–30. https://dl.acm.org/doi/10.1145/3374920.3374938.
22. Costa, J., Adams, A. T., Jung, M. F., Guimbretière, F. & Choudhury, T. *EmotionCheck: leveraging bodily signals and false feedback to regulate our emotions* in *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (ACM, Sept. 2016), 758–769.
23. Khng, K. H. A better state-of-mind: deep breathing reduces state anxiety and enhances test performance through regulating test cognitions in children. *Cognition and Emotion* **31,** 1502–1510. ISSN: 0269-9931 (Oct. 2017).
24. Ali, S. *et al.* A randomized trial of robot-based distraction to reduce children's distress and pain during intravenous insertion in the emergency department. *Canad. J. of Emerg. Medic.* **23.** Springer Nature, 85–93 (2021).
25. Alemi, M., Ghanbarzadeh, A., Meghdari, A. & Moghadam, L. Clinical Application of a Humanoid Robot in Pediatric Cancer Interventions. *Inter. J. of Soc. Robotics* **8.** Springer Science and Bus. Media B.V., 743–759 (2016).
26. Smakman, M. *et al.* Mitigating children's pain and anxiety during blood draw using social robots. *Electronics (Switzerland)* **10.** MDPI AG (2021).
27. Kitt, E., Crossman, M., Matijczak, A., Burns, G. & Kazdin, A. Evaluating the Role of a Socially Assistive Robot in Children's Mental Health Care. *Journal of Child and Family Studies* **30.** Springer, 1722–1735 (2021).
28. Crossman, M., Kazdin, A. & Kitt, E. The influence of a socially assistive robot on mood, anxiety, and arousal in children. *Professional Psychology: Research and Practice* **49.** APA, 48–56 (2018).
29. O'Brien, C., O'Mara, M., Issartel, J. & McGinn, C. *Exploring the design space of therapeutic robot companions for children* in *ACM/IEEE Int. Conf. Hum.-Rob. Interact.* (IEEE Computer Society, 2021), 243–251.

30. Samuelsson, I. & Johansson, E. Play and learning-inseparable dimensions in preschool practice. *Early Child Development and Care* **176,** 47–65 (2006).
31. Kozima, H., Nakagawa, C. & Yasuda, Y. *Interactive robots for communication-care: A case-study in autism therapy* in *Proc. IEEE Int. Workshop Robot Human Interact. Commun.* **2005** (2005), 341–346.
32. Peretti, G. *et al.* Coding with me: Exploring the effect of coding intervention on preschoolers' cognitive skills. *Annual Review of CyberTherapy and Telemedicine* **18.** Interactive Media Institute, 153–156 (2020).
33. Minato, T. *et al. CB2: A child robot with biomimetic body for cognitive developmental robotics* in *Proc. IEEE-RAS Int. Conf. Humanoid Rob., HUMANOIDS* (IEEE Computer Society, 2007), 557–562.
34. Singer, T. & Lamm, C. The social neuroscience of empathy. *Annals of the new York Academy of Sciences* **1156,** 81–96 (2009).
35. Preston, S. D. *et al.* The neural substrates of cognitive empathy. *Social neuroscience* **2,** 254–275 (2007).
36. Wicker, B. *et al.* Both of us disgusted in My insula: the common neural basis of seeing and feeling disgust. *Neuron* **40,** 655–664 (2003).
37. Singer, T. *et al.* Empathy for pain involves the affective but not sensory components of pain. *Science* **303,** 1157–1162 (2004).
38. Kuroda, T. *et al.* Sharing breathlessness: investigating respiratory change during observation of breath-holding in another. *Respiratory physiology & neurobiology* **180,** 218–222 (2012).
39. Masaoka, Y. & Homma, I. Anxiety and respiratory patterns: Their relationship during mental stress and physical load. *International Journal of Psychophysiology* **27,** 153–159 (1997).
40. Masaoka, Y. & Homma, I. The effect of anticipatory anxiety on breathing and metabolism in humans. *Respiration Physiology* **128,** 171–177 (2001).
41. Klausen, T. e. a. *Signalling Emotions with a Breathing Soft Robot* in *IEEE Int. Conf. Soft Robot., RoboSoft* (2022), 194–200.
42. Farhadi, U., Klausen, T., Jørgensen, J. & Vlachos, E. *Exploring the Interaction Kinesics of a Soft Social Robot* red. by Stephanidis C., Antona M. & Ntoa S. 292 pp. (Springer Science and Business Media Deutschland, 2022).
43. Belpaeme, T. *et al. Child-robot interaction: Perspectives and challenges* 452 pp. (2013).
44. Rabbitt, S., Kazdin, A. & Scassellati, B. Integrating socially assistive robotics into mental healthcare interventions: Applications and recommendations for expanded use. *Clinical Psychology Review* **35.** Elsevier, 35–46 (2015).
45. Lueder, R. & Rice, V. *Ergonomics for Children: Designing products and places for toddler to teens* 1 p. (CRC Press, 2007).
46. Elliot, A. & Maier, M. *Color psychology: Effects of perceiving color on psychological functioning in humans* 95 pp. (Annual Reviews Inc., 2014).
47. Braun, V. & Clarke, V. Using thematic analysis in psychology. *Qualitative Research in Psychology* **3,** 77–101 (2006).