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Social Robot' s Empathic Expressions as a Design Strategy for assisting people solving creative problems

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***Abstract*—In recent years, empathic agents have been explored widely in Human-Agent collaborative activities because empathy is essential for building relationships. Using social agents as creative support tools is also a popular research topic. Embodied agents as social agents have advantages in human-Agent collaborations in creative problem solving because of their embodied behaviors showing empathic cues, influencing people's feelings and facilitate the creative process. In this study, a non-humanoid embodied social robot was developed to test whether a social robot's non-verbal empathic behaviors have effect on helping people to solve creative problems. Each Participant faced two creative problems and experienced one of the three conditions: high empathic condition (HEC), low empathic condition (LEC) or neutral interactions of the social robot (CC). Results showed that the effects of robots' high empathic and neutral interactions significantly helped participants found the solutions for creative problems than the negative interaction. We also compared social perceptions of the robot across three conditions. The Warmth scores of the robot all increased and the Discomfort scores of the robot all descended except the low empathic group through two tasks. Our findings implicated that social robot's non-verbal empathic behaviors can be used as a design strategy to assist people in solving creative problems. Great potentials have been found for designing companion robots for Human-Agent collaborations in healthcare and educational applications.**

Keywords—Social Robot, Empathy, Non-verbal Behavior, Social Perception

1. INTRODUCTION

Human-Agent collaborations are more and more common. Because the technology revolutionizing our daily lives encompasses smartphones, virtual conversational agents, companion robots and autonomous vehicles. These advancements highlight a world where technological autonomy is becoming more prevalent, supporting various activities [1].

In the real world, robots interact with humans are increasing, highlighting the necessity for robots to engage naturally with people. To achieve this, integrating human norms into robotic systems is crucial[2]. Among the various proposed models of robotic behavior, those that conform to human social norms are generally favored. Studies show that embedding human-human interaction (HHI) norms and traits significantly enhances human-robot interaction (HRI). Specifically, robots that demonstrate empathy, a fundamental component[6] in HHI norm, are perceived as more acceptable, likable, trustworthy, supportive[3], friendly[1], and engaging[4]. This empathetic behavior also boosts the likelihood of humans engaging in long-term interactions with these robots[5]. Similarly, when a robot can comprehend a person's emotional state, it can modify its actions to align with the individual's affective condition and exhibit empathic responses.

Creative problem-solving is one of the most important distinctions between humans and other species. As robots increasingly collaborate with humans, utilizing robots to assist in creative problem-solving has become more popular[28-30]. Most existing human-robot collaboration systems still treat the robot as a device or tool, and the output of creative solutions largely depends on the human. Emotions play a significant role in the creative problem solving process and can influence a person's production of creative solutions[7] [63]. The social robot's behavior could influence individuals' perceptions and feelings when they experienced the creative problem-solving process. How do people view and feel robot's behaviors? And

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how can they utilize the robot's actions to assist them in completing creative problem-solving tasks? If a robot can be designed to empathize with humans, thereby affecting participants' feelings, it could possibly inspire people to generate more creative problem-solving ideas.

In this paper, we discovered the effects of different none-verbal empathic interactions of the social robots on people's creative problem-solving. We designed high empathic and low empathic interaction patterns, where the social robot either stimulated and motivated the process or disrupted it. And in control group, the robot gave neutral interactions. Our study has the three contributions:

1) We found that none-verbal empathic behaviors of social robot have positive influences on helping people solve creative problems.

2) New strategies were developed for fostering collaboration between humans and social robot.

3) Design implications of empathic social robot was discussed in different scenarios.

2. Background

2.1. Empathy Definitions

Empathy lacks a universally accepted definition, and its various interpretations can be categorized into three main groups[8]: (1) affective empathy ： one's emotional responding caused by other's emotional states, (2) cognitive empathy : one using comprehensive cognition to understand others' emotional states, and (3) integrating both emotional and cognitive aspect to comprehend others' whole situation[9]. Although emotional empathy can cause discomfort for the empathizer due to experiencing personal distress and discomfort while observing the target's negative emotions and circumstances [10], cognitive empathy typically results in less personal distress for the empathizer and more concern for the target [11]. The study showed that the empathy is a collection of constructs (Antecedents, Processes, Intrapersonal outcomes, Interpersonal outcomes) linking the empathizer's responses to the target [12].

In this paper, we imitated the psychological process of empathy and took the robot as an empathizer, displaying different empathetic behaviors (concern for the target or distress in itself) during the process of creative problem-solving towards to the target (participants).

2.2. Empathy Modulation

There are four primary categories of factors influencing empathic behaviors mentioned in the study by De Vignemont and Singer [13]: (1) Original attributes of the shared emotion (2) Empathizer's Characteristics (3) Relationships between the target and the empathizer (4) Situation context. These modulation factors, which Davis [14] indicated them as antecedents, may influence the outcomes of empathy.

In this paper, creative problem-solving serves as the contextual situation, with participants experienced various emotions throughout the process. The high-empathy or low-empathy behaviors of the robot can influence people's feelings, thereby either stimulating or inhibiting their creative problem-solving abilities. Additionally, these behaviors can affect how participants perceive their relationship with the robot.

2.3. Empathic Responses

Hoffman [15] underscores the importance of empathy in motivating prosocial actions and moral principles, with a particular focus on caring and justice as prosocial moral behaviors. Consequently, the action tendencies and behaviors that emerge from empathic processes can lead to helping and social behaviors, which serve as interpersonal empathic outcomes [16].

In this paper, when individuals encounter difficulties in the creative problem-solving process, the degree to which empathic behavior of the robot could be perceived as a form of prosocial behavior could influence participants' judgements in dealing with the creative problems.

3. Related Work

3.1. Empathic social agents for Human-Agent interactions

Empathy agents influence a lot on human perception and relationship between human and agent. Virtual conversational agents are first considered for presenting empathy. Sung Park [17] evaluated participants' behavioral synchronization in response to a virtual agent that exhibited emotional expressions according to the context through facial expressions, gestures, and voice. The study found that participants' facial expressions, both in terms of movement and intensity, were significantly more pronounced when interacting with the emotional virtual agent compared to a neutral one. Takahiro Tsumura [18] conducted an experimental investigation into the impact of empathy from agents on individuals' trust dynamics over time. The findings highlight that designing AI agents with empathy is a crucial factor in cultivating trust and facilitates the establishment of suitable trust relationships between humans and AI agents. Karl Daher [19] explored whether a medical chatbot demonstrating empathy is more beneficial to users. Two distinct medical assistant chatbots were developed with the objective of offering a diagnosis for physical health issues to users through brief conversations. The chatbot that exhibited empathy was rated significantly higher and was welcomed by most participants.

Studying embodied empathy agents are more popular in recent years. Ana Corrales-Paredes [20] examined the user experience aspect regarding the embodied robot, which could talk, move and showed gestures. The research revealed that integrating embodiment deign of the robot enhanced the user experience. And the key is designing robot's personality and behaviors. The study concluded that the appearance, movements, and communication style of robotic platforms significantly influence users' opinions and their interaction patterns. Ali Mollahosseini [21] introduced the development and human-robot interaction (HRI) studies of a robotic agent that simulates natural face-to-face interactions between humans and empathic agents. The findings suggest that users thought ExpressionBot was showing empathy because the robot did mutual eye gaze contact and accurately expressed facial expressions. Timothy W. Bickmore [22] designed an agent to imitate human conversational touch. This agent could physically touch users when speech and other nonverbal communication behaviors happened at the same time, and it presented empathy when users were in distress. The results suggest that users felt close with the agent because the agent touched them within an empathic, comforting interaction (without altering affective cues in other modalities). Jieun

Kim [23] examined the impact of nonverbal vocal cues on users' perceptions of the agent during speech interactions. The findings demonstrated that users got connection with the agent, because its' empathic feedback including nonverbal vocal cues, enhancing user's the attitudes of intimacy, similarity, closeness, amusement, and engagement towards the agent.

Researchers looked into strategy to build empathy between human and agent. Laurianne Charrier [24] conducted a preliminary study to investigate the impact of an empathy module on HRI. The study revealed that the "attention-based empathic module" influenced nine metrics: the duration of interaction, robot's perceived trustworthiness, number of disengagements, robot's perceived empathy, participants' sense of familiarity with the robot, robot's perceived intelligence, perceived comfort during the interaction, perception of the knowledgeability in robot, and perceived engagement level of the interaction. Marialejandra García-Corretjer [25] concentrated on cultivating empathy in HRI during a maze game through a series of collaborative strategies. The findings indicated that employing an active strategy of reflecting on the other's perspective resulted in people developing trust and positive expectations towards the robot.

All the aforementioned work indicates that empathy can bridge the gap between humans and robots. If the relationship between humans and robots deepens, it will facilitate individuals referring to the suggestions provided by robots or being influenced by the robot's behavior when robots assist in creative problem-solving.

3.2. Social agents' influences on people's creative problem-solving

Creativity refers to the capacity to generate novel and suitable artifacts or ideas for problem-solving [26]. Various manifestations of creativity include verbal forms such as writing, storytelling, composition, and discourse, as well as figural expressions like drawing, painting, and sketching [27]. In HCI community, Social agents serve as Creative Supportive Tools during Human-AI Collaboration. One study revealed that individuals took more time in music creation with drums when collaborating with the Mortimer robot [28]. Yaxin Hu [29] investigated how robot's social behaviors helped people's creative thinking and identified four traits of human behavioral associated with creativity in the interaction. Several studies have showed both non-verbal and verbal behaviors of social robots effectively prolong adults' engagement in creative activities and facilitate the generation of their own creative ideas [30]. Interactions between robots and children nurture children's creativity. Ali [31] devised two social interactions across three playful and collaborative tasks to evoke creativity in interactions between children and social robots. The creativities presented by the social robot were imitated by children, resulting in an increased level of creative expression [32]. Alves-Oliveira [33] showcased how children's creative abilities were stimulated during interactions with the robotic system YOLO, which exhibited both social and creative behaviors. Additionally, robots featuring light patterns have enhanced children's storytelling experiences [34].

Although there has been considerable research on using social robots as tools to enhance creative problem-solving, there have been few case studies examining the impact of empathetic behavior of social robots on creativity. This gap serves as the starting point for this study.

3.3. Social agents' verbal and none-verbal behaviors for social interaction and collaborations.

Many studies looked at social agents' verbal behaviors for social interaction and collaborations. For example, Jessy Ceha [35] examined how students were affected by a social peer robot's verbal expression of curiosity. The findings revealed the robot's curiosity was identified by the participants, and caused emotional and behavioral curiosity contagion in the students. Health is a popular application area to develop human-agent interaction. Dina Utami [36] designed a fully automated robot for couples counseling, with a particular emphasis on identifying and processing "collaborative responses." The robot was found to effectively facilitate counseling sessions, promoting intimacy between romantic partners. Yao-Lin Tsai [37] developed a service robot aimed at reminding participants to focus on their nutritional health, physical and mental needs through three weeks. The study revealed that participants' mood and overall workplace satisfaction improved by beneficial effects of a seamless service robot experience. Yao-lin Tasi [38] investigated the potential advantages of social robots in promoting healthy human behaviors, while also exploring how street-performance inspired techniques and a touch of humor could enhance the overall quality in HRI experience. Compared to verbal behaviors, non-verbal behaviors are relatively less studied.In this paper, we mainly focus on social agents' none-verbal behaviors for social interaction and collaborations.

A lot of studies focus on how emotions elicited by the robot's none-verbal movements. Martin Saerbeck [39] studied how affect elicited by Robot Motion was perceived by people. Motion parameters were found to have a strong relation between and attribution of affect. Tek-Jin Nam [40] did the mapping between robot's physical movements and emotions. The findings illustrated that physical movement can readily evoke certain emotional responses. Specifically, the study revealed a positive correlation between emotions in both pleasure and arousal dimensions and movement speed.

Gesture designs of social robot is curial for human-agent communication. Guy Hoffman [41] discovered a robot's accompany affected people's music enjoyment. Robot gestures were designed to make and maintain eye-contact and dance moves, using nonverbal gestures. The results showed that robot positively affected song liking. And people felt the robot more like a human and similarities between them. Maria Teresa Parreira [42] examined the role of a robot's listening behaviors in assisting problem-solving session. They assessed the influences of the robot's presence on users' engagement in verbalizing their thoughts and behaviors during the task. Robot Duck Edith Law [43] explored how unexpected robot behavior can elicit curiosity and affect participants' trust and engagement when they interacting with Recycle (a service robot). Findings indicated that surprise triggered information-seeking behavior associated with curiosity, leading to increased engagement but decreased trust. Robot's gesture had effects on people's social perception towards these social robots. Jin Niu [44] investigated the how people perceive robot's personality traits based on their gestures (four types were developed). Additionally, the study compared the gesture design guidelines needed for four specific scenarios: shopping, home, education, and security. Maha Salem [45] examined the humanoid robot gave non-verbal behaviors congruent or incongruent accompanying the speech. Findings revealed that as long as the robot used co-verbal gesture. Participants preferred the robot as more anthropomorphic, more likable, and intended more for future communicate compared to the robot's no-gesture instructions.

Robot's movements also a played curial role for human-agent interactions. Brian Ka-Jun Mok [46] examined the significance of designing expressive movements of socially appropriate robots for human collaboration. Findings suggested that participants engaged and showed more interest on expressive robots in the interaction. While the robot's proactive behavior influenced the participants' perception of robot's social status, whereas expressiveness did not. Abhijeet Agnihotri [47] evaluated the effectiveness of four motion strategies employed by a robot in attracting passersby to play chess. Individuals perceived the ChairBots as friendly and somewhat resembling dogs. Heather Knight[48] explored how robotic chairs used motion as an signal to share spaces with people. The study found that the when the robot move forward or backward, conveying the robot's intentions effectively. However, it also identified a balance between clarity and politeness, where people regarded direct communication of the robot was aggressive. The key design for robot is to make clear communication at first, while avoiding over-communication later. Yusuke Kato [49] modeled robot's polite approaching behaviors in a shopping mall, which make robot successfully initiated interaction with pedestrians. In a study by Rond [50], a game was introduced where an robot collaboratively constructs a narrative with an improviser using meaningful motions. The results showed that competent adults regarded a basic robot as a teammate, its' positive support influenced the storyline. Additionally, participants offered valuable insights into robot motion. Stephen Yang [51] designed a robot served as a trash barrel and evaluated its' interactions with people in public to gain insights into the implicit protocols. Observations and interviews revealed the following: a) when people want the robot's services and when the robot actively move to show its intentions, individuals are most receptive to the robot's presence; b) people tend to attribute intentions and desires to the trash barrel, forming mental models of its behavior; c) people feel the robot is in autonomous control rather than remote operation because the wrong navigations; and d) same errors and strange behavior elicited mixed responses, ranging from indifference to endearment.

To achieve effective social interaction and collaboration between robots and humans, it is crucial to design empathetic behaviors that evoke emotional responses from participants. While verbal communication remains the most common approach in designing empathetic interactions, non-verbal behaviors such as gestures and movements also play a significant role. Drawing from previous examples, we focused on designing non-verbal empathetic behaviors, specifically robot gestures and movements, due to constraints of time and technology. This study explores whether different non-verbal empathetic behaviors can influence participants' perceptions and outcomes when solving creative problems.

4. Robot apparatus and empathic behavior Design

The robot is composed of an overall cylindrical body base, a neck and a head. It stands at approximately 30 cm tall, weighs around 1.3 kg. There are two layers inside the cylindrical body of the robot (Figures 1). For upper layer, an

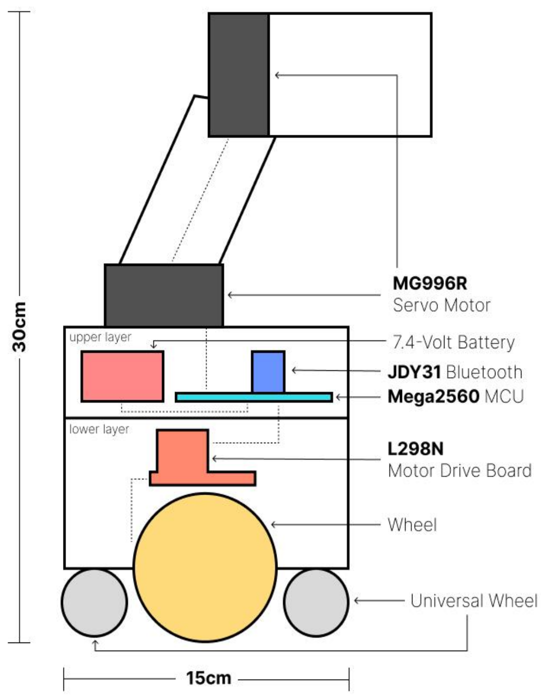

Figure 1. Diagram describing the components of the robot

Arduino Mega 2560 is put inside and used as a MCU with a 7.4-volt battery providing the power. A JDY 31 Bluetooth module is connected with Arduino Mega 2560. We used MIT App Inventor to design an operation app installed on an Android phone. By connecting the Bluetooth, the robot was controlled remotely. For the other lower layer, The L298N module is fixed to control the robot's wheels in order to make the robot move forward and backward or do circular motions. Two MG996R servo motors are connected with metal skeleton, fixed on the cylindrical body base, enabling joint movement with two degrees of freedom. Thus, the robot can perform gestures like leaning and nodding. All control programs were written in Arduino software and uploaded to the MCU. Aesthetically, the social robot is crafted in a non-humanoid form to avoid the Uncanny Valley effect [52]. Studies have demonstrated that non-humanoid form design positively influences interactions, particularly with minimal communication modalities such as nonverbal gestures [53] [54]. To prevent the wiring and equipment from being exposed to participants and affecting their perception, we wrapped the robot's body with foam to create its skin.

According previous studies about mechanisms of empathy. We built three principals: (1) Behaviors of the robot must follow the human-human interaction (HHI) norms in order to let people easily get empathic cues. The behaviors should be as expressive and obvious as possible. (2) The high empathic behaviors should be regarded as prosocial actions perceived by participants (3) Personality of the robot and the relationship between the participant and the robot should be considered. Viva Sarah Press's work [55-56] gave us inspirations for designing robot empathic behaviors.

We did a pilot study to find which gestures and movements are suitable for showing empathy or not. 10 participants from Zhejiang University took part in the experiment. They were told to imagine under the circumstance when they solved the creative problems, which behavior presented by a robot was showing empathy to them. 10 gestures and movements were ranked on a 1-7 scale from least empathic behavior to most empathic behavior. The differences relied on the robot facing or not facing and leaning or not leaning towards the participant, the speed of the movement, which situation the robot rotate or not, also the behavior patterns. Each participant experienced all designed behaviors patterns, which were presented in a random order. Based on the test outcomes and principles we set, we build three behavior sequences under three different conditions based on the study (Table 1).

TABLE I. INTERACTION PATTERNS FOR EXPERIMENTAL CONDITIONS

Conditions	Interaction Patterns
Behavior in high empathic condition(HEC)	1) Moving forward to the participant 2) leaning forward and looking at the participant 3) Moving forward and backward to show empathic concern
Behavior in low empathic condition(LEC)	1) Spinning in a circle when the participant to show anxiety
Behavior in control condition(CC)	1) Facing the participant and does not do any gesture or movement.

Figure 2. High Empathic Behaviors

Figure 3. Low Empathic Behaviors

- Behavior showing high empathic (Avg: 6.2; SD: 1.06): when participants encountered problems, robot's facing and leaning actions let they felt they were concerned by the robot, although no words were presented. And moving forward and backward means the robot share the same emotion of anxiety as the participants facing the problems.
- Behavior showing low empathic (Avg: 2.35; SD: 1.48): The robot spinning in a circle alone caused the negative impression. Most participants felt that the robot did nothing help but disturbed them. Even though the robot tried to show empathy, while the actions looked self-centered.

5. METHOD

5.1. Participants

30 participants (12 males and 18 females) took part in the study, all students from Nanjing University of the Arts, with an average age of 24. Each condition included ten participants. Each participant only experienced one of three experimental conditions. The condition was randomly assigned to each individual. All participants were provided informed consent and were assured that all recorded material would be confidential and they could quit the experiment anytime during the process of the experiment.

5.2. Setup

The experiment was conducted at Nanjing University of the Arts. To simulate natural robot behavior, we utilized a Wizard of Oz (WOZ) system. The operator looked at the video camera and controlled the robot in a different room, making participants believe the robot was functioning autonomously (Figure 4). Figure 5 illustrates the experimental setup in detail: an experimenter and a participant sat beside a table. The robot

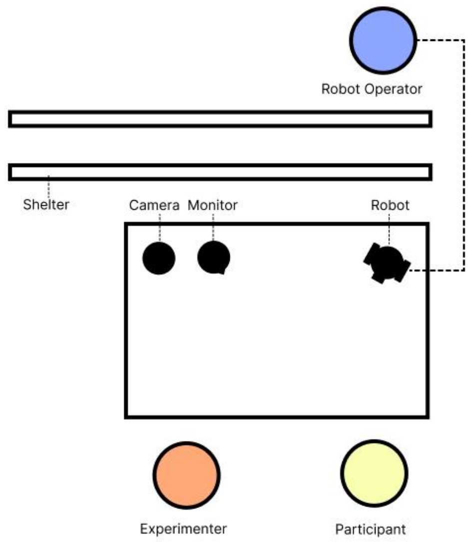

Figure 4. Experiment Setup

was standing in front of the participant. Participants were guided by the experimenter to complete two tasks. The operator, situated in a separate room and hidden from the participants' view, controlled the robot's actions based on real-time video footage capturing both the participants and the robot.

5.3. Experimental Design and Hypotheses

Creativity is defined as the capability to generate both novel and suitable ideas or artifacts for problem-solving [26]. Creativity manifests in various forms, such as verbal creativity (writing, storytelling, composition, discourse) and figural creativity (drawing, painting, sketching) [27]. Creativity is characterized by fluency, flexibility, and originality [57]. In this study, two tasks were selected to assess creativity: one verbal creativity and one figural creativity. Participant were expected to use divergent thinking to get more scores in the Association Task (AT) and the Alternative Object Use Task (AOUT). The high scores showed the creative problem-solving abilities each participant had. In the first task (AT), participants saw the robot. Participants were instructed to select a role of the robot based on the formed impression during the first task and filled out the RoSAS Scale. Then participants proceeded the second task (AOUT). Each participant engaged in two tasks under different conditions and filled out the RoSAS Scale again and got a semi-structured interview after completing both tasks. The entire experiment lasted approximately 50-60 minutes.

We conducted a One-way ANOVA experiment with three conditions (Table 1). In the high emphatic condition (HEC), the robot consistently exhibited high empathic behaviors to encourage and inspire participants (Figures 2). Conversely, in the low empathic condition (LEC), the robot consistently displayed low empathic behaviors to disrupt participants (Figure 3). In the control condition (CC), the robot remained passive and simply observed the participants. Participants filled out the RoSAS Scale after the first task and filled it again after the second task. We compared the changes of warmth and discomfort scores of RoSAS across the three groups in two stages to see whether the social perceptions of the robot change through the experimental process. Another one-way ANOVA was performed.

Previous research has shown that high empathy can bridge the gap between humans and robots, thereby bringing better positive feelings to participants [23-25]. Positive emotions can facilitate the resolution of creative problems [58-59]. Conversely, the negative emotions caused by low empathy in robots can be transferred to participants [10], hindering their ability to solve creative problems [59-60].

Figure 5. Experiment Environment

Thus, we formulated the following hypotheses:

(H1): The Creative Scores of participants in the HEC will surpass those in the LEC and CC in two tasks.

(H2): The Creative Scores of participants in the CC will exceed those in the LEC in two tasks.

(H3): Participants regard robot as anthropomorphic accompany will score higher in creative scores of the second task than Participants regard robot as an object.

(H4): Warmth scores of RoSAS Scale in the HEC will be higher than the scores in the LEC and the CC in two tasks.

(H5): Discomfort scores of RoSAS Scale in the LEC will be higher than the scores in the HEC and the CC in two tasks.

5.4. Measures

The creative outcomes in the first task, known as the Associations Task Creative Score (ATCS), was assessed based on the diversity (T) and quantity (N) of round-shaped objects listed by participants. The scoring formula used was T * 0.7 + N * 0.3. For the Alternative Object Use Task Creative Score (AOUTCS), five experts in interactive, industrial, and graphic design from universities and design companies evaluated each participant's creations. They rated each piece on a scale from 1 (least creative) to 5 (most creative). Participants received an additional point for reusing specific object candidates (tin wire and cookies) in their creative process. The total scores from all creations produced by a participant were summed to determine their final score for the second task. For both tow tasks, the higher the score, the stronger the participant's ability to solve creative problem.

Carpinella and Wyman et al. developed the Robotic Social Attributes Scale [61]. It was utilized in this study due to its ability to gauge social perceptions of robots [62]. This scale consists of 18 items that address three primary dimensions of social perceptions of robots: warmth, competence and discomfort. In this study we chose two dimensions: warmth and discomfort. Participants evaluated each item in a random order on a 5-point Likert scale, ranging from 1 ("not at all") to 5 ("very much so").

5.5. Procedure

Upon arrival, the purpose and procedure of the experiment were briefed to participants. As participants entered, the robot would raise its head and make eye contact with them. Subsequently, participants signed a consent form and took a five-minute break to relax.

Participants were told to generate associations related to "round shapes" and list as many round-shaped objects as possible in the first task. During this task, the robot displayed specific pre-designed behaviors outlined in Table 1. After completing the first task, participants selected one impression word from six different options. And filled out the RoSAS Scale. They then proceeded to the second task, where they were presented with four object candidates (a cap, adhesive tape, tin wire, and cookies) and instructed to choose one. Participants then used the chosen object to create new graphics, producing at least two and at most four works. The robot's behavior during the second task was consistent with the participant's assigned condition. After completing both tasks,

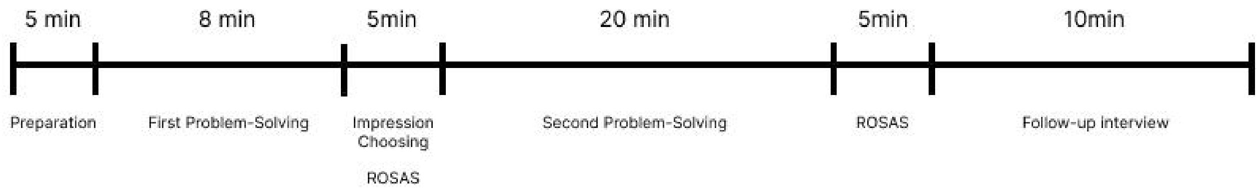

Figure 6. Experiment Producer

participants filled out he RoSAS Scale and underwent a semi-structured interview. (Figure 6).

6. Results

In the Associations Task (AT), across three conditions, no significant differences were found in creative scores (F (2,27) = 1.262, p = 0.299) (Figure 7). The mean creative scores for the High Empathic Condition (HEC) group (M = 19.10, SD = 4.42) were higher than those for the Control Condition (CC) group (M = 18.35, SD = 4.55) and the Low Empathic Condition (LEC) group (M = 15.78, SD = 5.64). Details can be seen in Appendix 1.

In the Alternative Object Use Task (AOUT), significant differences in scores were observed among the different conditions (F (2,27) = 5.632, p = 0.009) (Figure 8). Post-hoc analyses using the LSD method for pairwise comparisons (Table 3) indicated significant differences between the LEC and both the HEC (p = 0.005) and the CC (p = 0.01). However, significant difference did not appear between the HEC and the CC (p = 0.786) in terms of creativity. The mean creative scores for each condition. Therefore, hypotheses 1 and 2 were both partially supported. Details can be seen in Appendix 2.

In terms of choosing impression of the robot after the first task. 12 participants preferred using anthropomorphism descriptions about the robot (friend, assistant, servant). 18 participants preferred describing the robot as objects (machine, device, tool). No significant results of creative scores in second task were found between the anthropomorphism (M = 9.68, SD = 2.21) impression and the object impression (M = 8.58, SD = 2.53) (Figure 9). The hypotheses 3 was denied.

6.1. Subjective Perceptions of the robot

The ANOVA analysis revealed that statistically significant difference in first Warmth scores (F (2,27) = 3.921, p = 0.03) across three conditions. No statistically significant difference was found in second Warmth scores (F (2,27) = 3.061, p = 0.06 across three conditions.

The Post Hoc Tests (Multiple Comparisons LSD) revealed that the first Warmth scores in HEC statistically significantly was higher than the LEC (p = 0.03) and CC (p = 0.02). The second Warmth scores in HEC statistically significantly was higher than the LEC (p = 0.02). No significant effect was discovered between the HEC and CC. The Hypothesis 4 was

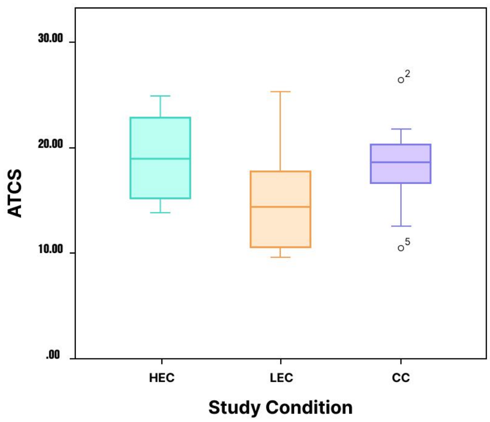

Figure 7. Association Task Creative Score

partially supported. The first discomfort scores in LEC statistically significantly were higher than the CC (p = 0.00). No significant effect was discovered between the LEC and HEC. The second discomfort scores in LEC statistically significantly were higher than the HEC (p = 0.00) and CC (p = 0.00). The Hypothesis 5 was partially supported. Figure 10 and Figure 11 indicated how the Warmth scores and Discomfort scores changed between two stages. Descriptive statistics of the Warmth score and Discomfort score are shown in Appendix 3.

6.2. Semi-structure Interview

Q1: What information do you believe the robot's actions conveyed?

Q2: Do you feel the robot's behaviors conveying emotions?

Q3: How do you perceive the robot?

The arrangement of AT was designed to acquaint participants with the robot. Different participants exhibited vastly different reactions during AT. Twelve participants believed that the robot's actions conveyed stronger emotions, with two participants explicitly stating that the robot's negative actions expressed strong affirmation. Eight participants from the HEC felt the caring from the robot. Five participants from LEC thought the robot anxious because it kept spinning. Most participants from control condition gave the robot a natural description.

Regarding high empathic influences, one participant (P12, who chose "friend" in the impression selection) stated, "I was influenced. I felt like the robot was curious about me, wanting to be my friend." Another participant (P20, who chose "assistant") remarked, "When I was feeling uninspired, its movements helped me relax mentally and provided me with some inspiration." Regarding low empathic influences, one participant (P7, who chose "servant") said, " I was unsure of the robot's next move, which interrupted my mind." Another participant (P18, who chose "device") mentioned, "I felt that during task one, the robot was not significantly associated with the task. I thought the robot would speak and it turned out not."

Q4: Did the impression you selected affect your second task?

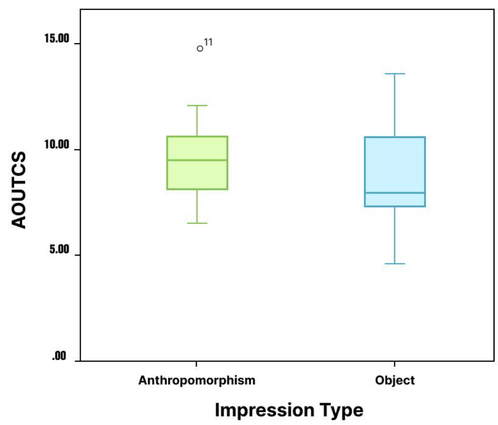

Figure 8. Alternative Object Use Task Creative Score

Q5: Were you influenced by the robot during the creative process? If yes, was this influence positive or negative?

Twenty participants indicated that the impression about robot's reactions from AT affected their performance during the AOUT. Six participants stated that they gain subjective preference towards the robot after the AT, the robot's reactions inspired them in AOUT.

Sixteen participants provided more positive responses, believing that the robot's influence was mostly positive. The participant who believed that the negative actions expressed strong affirmation (P11, LEC) said, "During task one, I didn't observe the robot, but its actions in AOUT had a positive influence. It sparked inspiration, spinning provided emotional value." Another participant (P23, HEC) stated, "Overall, task two was positive. The robot seemed like lively, which inspired me. " Ten participants provided neutral responses. One participant (P15, CC) said, " There was some impact. I attempted to disregard it, but the robot's actions pushed me to think more quickly. The intensity of its movements, sounds, and noises made me somewhat irritable, and I could see it in my peripheral vision. However, my creative process sped up, which I found to be beneficial." Other participants who provided neutral responses felt that the robot's presence didn't have much influence because they were very focused during creation or had become accustomed to its presence after understanding its actions, with no instances of inspiration being sparked or hindered. Four participants provided negative responses. P1 (LEC) felt, "The robot attracted my attention, but there were no additional creative results, which wasted time and patience."

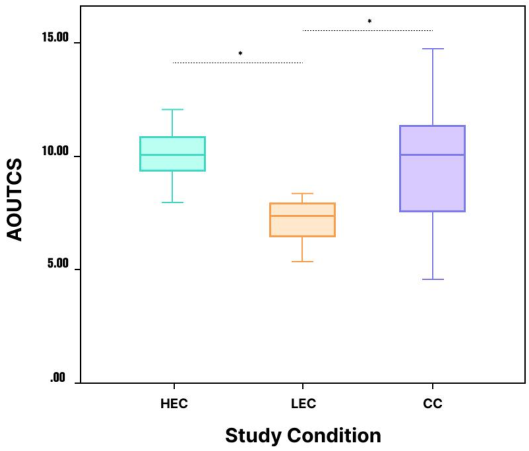

Figure 9. Creative Score between two impression types

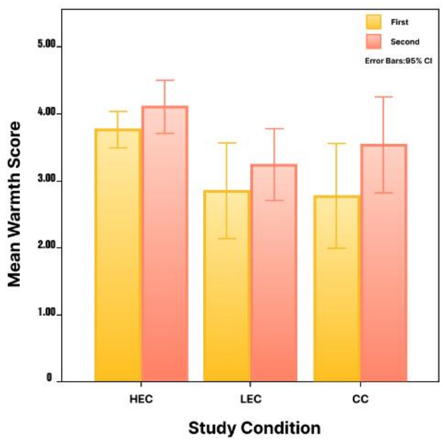

Figure 10. Perception of Warmth scores in two tasks

7. Discussion and Limitation

7.1. Effects of social robot's none-verbal empathic behaviors on creative problem-solving

None of the participants had encountered the robot's form before the two tasks. The initial Association Task (AT) was designed to familiarize participants with the robot. Although no significant differences were observed among the conditions during the AT, it was evident that both high empathic and natural behaviors exhibited by the robot inspired participants more than the low empathic behaviors. Participants believed that the form, the gestures and the movements performed by the robot was trying to inspire them in solving creative problems. P10 (HEC) remarked, "When I was stuck in creating, the robot's movements provided me with some inspirations. I thought the robot is trying to help me." On the contrary, P11 (LEC) said, "I didn't know why the robot seemed more anxious than me, which blocked my train of thought." Most participants form CC thought the robot did not help with the task.

In the AOUT, top eight participants who got high scores were all from PC and CC groups. In HEC, seven participants could feel the robot was caring them because of the behaviors of moving forward and leaning. three participants mentioned they did not feel the influence by the robot because they were focusing on creativity task. In CC, half participants mentioned the same reasons as the participants from HEC why they were not influenced, P19 (CC) said, "the robot was like any ordinary object at home." The other half gave positive responses for robot's influences. They all mentioned that they were getting along with the robot after the first task. Even the robot did not act, they still felt someone was accompanying with them. The quite behavior was taken as a good help for some participants, giving them chance to focus the problems. the AOUT scores varied a lot from participants in CC. Considering the robot did nothing during the task, performances were only relied on participants' own personal abilities. In LEC, some participants thought the spinning was annoying, while some felt the robot were showing anxiety. This behavior was like a human action, trying help but nothing can be done. Two participants thought that the robot's influence was neutral to solve creative problems. Among the remaining eight participants, half generally believed that the robot's behavior had a positive impact on creativity, while the other half held the opposite opinion. P7 (LEC) believed, " The robot's actions had a negative impact. While it did spark some creative ideas, I felt that this inspiration was counterproductive, as my ideas were constrained. "

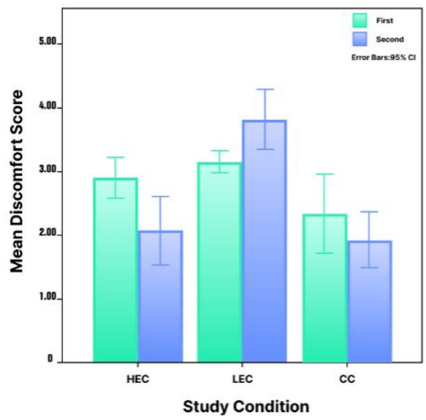

Figure 11. Perception of Discomfort scores in two tasks

Participants interpreted the robot's different empathetic behaviors differently. When participants gave a positive interpretation, they used the robot's actions and appearance as inspired creative material. When participants gave a negative interpretation, they were interfered during their creative activities. Some participants from HEC or LEC were not affected by the robot and only focused on the creative problems. So they thought the robot's influence was neutral. In control condition, participants could easily focus on solving creative problems because the robot almost did nothing. While some participants form CC thought no impact from the robot could be regarded as positive influence.

7.2. *Robot's behaviors cause participants' feelings during creative problem-solving*

In each condition, participants experienced positive, neutral, or negative emotions during their creative tasks. We chose to analyze all participants collectively.

Across all conditions, sixteen participants felt positive emotions, though for varying reasons. ten participants (5 from HEC, 2 from LEC, 3 from CC) felt positive due to the inspiration provided by the robot. As P13 (LEC) noted, "Although the robot's behavior made me mistakenly think I wasn't doing well, I quickly adjusted my mindset and found inspiration in the robot's spinning, this cheered me a lot." six participants (3 from HEC, 1 from LEC, 2 from CC) felt positive because of the robot's friendly social behaviors. P25 (HEC) mentioned, "During the creative process, I felt that the robot's spinning expressed support and affirmation for my work. This positive and pleasant feeling helped open my mind and engage in creative reasoning."

Conversely, seven participants (5 from LEC, 2 from CC) felt negative emotions due to the robot's behaviors, which made them feel anxious, irritable, and occasionally scared. Seven participants (2 from PC, 2 from LEC, 3 from CC) felt neutral emotions. They believed the robot was helpful or at least did not disrupt the creative process, while their moods remained stable.

We hypothesized that participants' different personalities led to varied emotional reactions when encountering the robot's behavior patterns. This explains the differing emotional responses across the three conditions. We also discovered that even though participants were inspired and experienced various emotions across the conditions, they demonstrated better outcomes under the robot's high empathic and neutral behaviors. Participants might have been consciously or unconsciously influenced by the different behavior patterns. In comparison to the AT, the robot significantly affected participants more during the AOUT. This suggests that participant's perceptions and emotions varied regarding the robot's various behavior patterns, which influenced the creative process.

7.3. *Perceptions of the robot influences the creative problem-solving process*

After the AT, participants were asked to choose a word from either the anthropomorphism type (friend, assistant, servant) or the object type (machine, device, tool) that best described their initial impression of the robot. This was done to see whether the participants' perceptions of the social robot affected their performance during the following AOUT. Even though no significant results were found between two impression types (Figure 8). We still got feedbacks from the interview seeing that 70% of the participants (21 out of 30) were indeed affected by their impressions. Most Participants regarded the robot as an object, the choices were made by participants all from the LEC and CC. Even though we also designed low empathic behaviors(spinning) following the human norms, many participants took these behaviors as self-related actions of a machine or a device, someone thought it went wrong. The robot in CC just stood, no wonder causing the impression of a still object from participants. Participants from the HEC regarded the robot was anthropomorphic. Because the high empathic behaviors of the robot (moving forwarding, leaning) we designed were like the normal human behaviors.

We leaded the participants to fill out the dimension of Warmth and Discomfort from RoSAS Scale respectively after each task. Participants at first were not familiar with the robot. When finishing the AT, the high empathic behaviors of the robot got better impressions from participants in Warmth. While participants had similar impressions about low empathic interactions and natural interactions. Participants felt the robot, who giving low empathic behaviors, more uncomfortable than other two conditions. After the AOUT, Warmth scores all increased and Discomfort scores descended except the participants got low empathic interactions. It turned out that after getting familiar with the robot, participants' attitudes changed towards the robot. It subsequently leaded that the autonomy of the participants increased through the tasks. Compared to the Association Task (AT), they were more actively to get influenced by the robot during the Alternative Object Use Task (AOUT). Participants' scores of AOUT had significant difference across three conditions, demonstrating that their perceptions of the robot significantly impacted participants to solve creative problems.

7.4. *Design implication*

Empathic behavior designs made robots have a stronger impact on people's problem-solving abilities. Some people took the robot as a real living thing. Even though not all participants believed the robot's behaviors helping them in terms of the specific task. They still welcomed the social robot embedding into their normal lives. Robot's neutral states gave participants autonomy in creation when the robot just stood beside them and did nothing. In the future, the development of robotic behaviors should take into account various contexts to identify which behavior patterns can most effectively support people in specific activities. Designing an educational companion robot for children requires a different approach compared to creating a companion robot for design professionals. Empathy is one the fundamental factors for people getting connected [6]. The development of designing empathic behaviors of the social robots could be used into many application scenarios such as Health care, entertainment, and education, where robots must interact with humans in a natural course. To achieve truly engaging interactions, it is essential to incorporate and model empathy.

Familiarity with a robot significantly impacts collaboration strategies. The robots were unknow to the participants and people were passively influenced at the first time. However, as they interacted more with the robot, people and the robot got connections, enhancing participants intentions to cooperate further more with the robot. Therefore, it is crucial to consider the social characteristics of robots. Developing strong relationships between humans and social robots can foster interaction details. In the realm of human-agent collaboration, the non-verbal behaviors of social robots are as crucial as their conversational skills in fostering human problem-solving abilities. Gestures and movements that convey a robot's emotional responses offer social cues that can consciously or subconsciously influence people's thoughts and actions, as demonstrated in prior research [41]. The different empathetic behaviors cause participants' different feelings, participants were either boosted or impeded in creative problem- solving. Therefore, the design of a robot's behaviors, especially those incorporating emotional information, should be meticulously crafted for effective collaboration. And combining verbal and none-verbal behaviors together, the social robot will act more like a normal human, leading a vivid interaction with people, enhancing people's ability to solve different creative problems.

7.5. Limitation and Future Work

All participants were from the same university, we did not distinguished differences in gender, age, and occupation. The design of empathic behavior patterns of the social robot were also simple. Additionally, how participants' personalities affected problem-solving outcomes were not examined. In future studies, we will explore more behavior patterns or utilize multimodal approaches for social robots and consider genders, ages, and occupations of participants in different situations of creative problem-solving. To avoid potential learning or fatigue effects, we used between-subjects analysis. However, the number of subjects was insufficient. We will add the number of participants to at least 20 people or more for each experimental condition for further studies or gave enough rest for participants between each sub-experiment in order to reduce learning and fatigue effects.

8. CONCLUSION

In this paper, we explored the potential impact of a social robot's non-verbal empathic behaviors on human creative problem-solving. We designed specific interaction patterns for the robot to either display empathy or remain neutral. A comparative study was conducted under three distinct conditions. The results demonstrated that the robot's empathic behaviors significantly influenced participants' creative processes in both the Association Task and the Alternative Object Use Task. High empathic and neutral behaviors were particularly effective in enhancing participants' outcomes. As participants became more familiar with the robot through these tasks, they developed positive attitudes towards it in terms of social perception. Based on findings, design strategies were discussed and design potentials for social robots in different scenarios.

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AVAILABILITY OF DATA

Not applicable.

ETHICAL STATEMENT

All participants provided written informed consent prior to participation. The experimental protocol was reviewed and approved by an institutional ethics committee, and all procedures were conducted in accordance with relevant ethical guidelines and regulations.

AUTHOR CONTRIBUTIONS

Sheng He conceived and supervised the study, designed the overall research framework and experimental conditions, and led the analysis and interpretation of the results, while Zhenyu Liu developed the embodied social robot and implemented the non-verbal empathic behaviors, E Tang conducted the user experiments, data collection, and statistical analysis, and Cheng Yao contributed to experimental design refinement, result interpretation, and manuscript preparation.

Competing Interests

The authors declare no competing interests.

APPENDIX 1 DESCRIPTIVE STATISTICS OF ATCS AND AOUTCS

		N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Associations Task Creative Score (ATCS)	HEC	10	19.10	4.42	1.40	13.90	24.90
	LEC	10	15.78	5.64	1.78	9.70	25.40
	Control	10	18.35	4.55	1.44	10.50	26.50
	Total	30	17.74	4.95	0.90	9.70	26.50
Alternative Object Use Task Creative Score (AOUTCS)	HEC	10	10.06	1.34	0.42	8.00	12.10
	LEC	10	7.19	1.01	0.32	5.40	8.40
	Control	10	9.53	2.15	0.68	7.60	12.80
	Total	30	8.93	1.98	0.36	5.4	12.80

APPENDIX 2. POST HOC TESTS — MULTIPLE COMPARISONS — LSD

Dependent Variable	(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.
Associations Task Creative Score (ATCS)	HEC	LEC	3.32	2.19	0.14
		Control	0.75	2.19	0.73
	LEC	HEC	-3.32	2.19	0.14
		Control	-2.57	2.19	0.25
	Control	HEC	-0.75	2.19	0.73
		LEC	2.57	2.19	0.25
Alternative Object Use Task Creative Score (AOUTCS)	HEC	LEC	2.87*	0.94	0.00
		Control	0.53	0.94	0.46
	LEC	HEC	-2.87*	0.94	0.00
		Control	-2.34*	0.94	0.003
	Control	HEC	-0.53	0.94	0.46
		LEC	2.34*	0.94	0.003

APPENDIX 3. DESCRIPTIVE STATISTICS OF THE WARMTH SCORE CHANGES AND DISCOMFORT SCORE CHANGE

		N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
First Warmth Score	HEC	10	3.78	0.38	0.12	3.10	4.30
	LEC	10	2.87	1.00	0.32	1.20	4.20
	Control	10	2.78	1.10	0.35	1.20	4.20
	Total	30	3.14	0.97	0.18	1.20	4.30
First Discomfort Score	HEC	10	2.89	0.46	0.14	2.30	3.80
	LEC	10	3.14	0.24	0.08	2.80	3.50
	Control	10	2.33	0.87	0.27	1.10	3.40
	Total	30	2.79	0.66	0.12	1.10	3.80
Second Warmth Score	HEC	10	4.12	0.57	0.18	3.10	4.90
	LEC	10	3.26	0.76	0.24	2.00	4.60
	Control	10	3.55	0.99	0.31	1.50	4.50
	Total	30	3.64	0.85	0.15	1.50	4.90
Second Discomfort Score	HEC	10	2.07	0.75	0.24	1.20	3.80
	LEC	10	3.81	0.66	0.21	3.00	4.60
	Control	10	1.92	0.62	0.20	1.20	3.50
	Total	30	2.60	1.09	0.20	1.20	4.60