Who's Better? Exploring the Effects of Social Comparison in HRI on Self-Esteem and Self-Efficacy

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***Abstract*—As robots become common in our everyday lives, their presence can impact how we view ourselves due to humans' inherent tendency for social comparison. This study explored how performing a simple search task alongside a robot can influence self-esteem and self-efficacy. These basic psychological constructs are known to contribute strongly to human well-being. Participants were asked to look for specific target symbols printed on cubes, while a robot performed a similar independent task next to them. They were assigned to one of three conditions: *Upward comparison*, where the robot's performance was perceived as superior; *Downward comparison*, where the robot's performance was perceived as inferior; or *Equal performance*, where the robot's performance was equal to their performance. While there was no direct interaction with the robot, performing a task next to it led participants to automatically engage in social comparison and compare their performance and capabilities to those of the robot. Our findings reveal that participants in the *Upward comparison* condition experienced a decrease in self-esteem, self-efficacy, and performance accuracy compared to the *Downward comparison* and *Equal performance*. The results suggest that even without direct interaction, simply performing a task alongside a robot can significantly impact individuals' basic psychological constructs and the way they perceive themselves. As robots increasingly share environments with humans, this study highlights the importance of considering people's tendency for social comparison when designing human–robot interaction and the extent of its impact on humans' well-being.**

***Index Terms*—Self-esteem, Self-efficacy, Social comparison, Human–robot interaction, Robot, Search task**

I. Introduction

As robots become increasingly integrated into our daily lives, their presence in our environments is expected to rise dramatically. Robots are predicted to share spaces with us in our homes, public space, and workplace [1]–[6], either collaborating with us [7], [8] or performing separate tasks alongside us [2], [9]–[11]. While most Human-Robot Interaction (HRI) studies focus on designing high-quality collaborations with robots [7], [12], [13], there has been a growing interest in the impact of robots that share people's environment and perform tasks next to them, without direct collaboration [8], [14], [15]. This context introduces new challenges due to humans' inherent tendency for social comparison.

Fig. 1. Performing a task with a robot that demonstrates superior performance.

When individuals share a space with others, they typically demonstrate an automatic tendency to assess their abilities and achievements relative to those around them [16], [17], a phenomenon known as "social comparison." Although the comparison of our performance with that of others is commonly not informative or helpful, social comparison is a basic psychological process, and people automatically use others' performance as a reference point for evaluating themselves [18]–[21]. This tendency is believed to serve a fundamental need for self-evaluation, allowing one to maintain a stable sense of self [16], [21], [22]. The impact of social comparison on individuals can vary depending on the direction of the comparison. When people compare themselves to others they perceive as more competent and superior, known as "upward comparison," they often report a negative experience and feeling worse about themselves [23]–[26]. The negative impact is associated with thoughts about under-performance, which capture attentional resources [27]. This impact on performance may be closely related to the mere presence effect [28], a phenomenon already demonstrated in HRI [29]. On the other hand, comparing yourself to others who are perceived as inferior and less competent, known as "downward comparison," typically leads to a positive experience and feeling better about oneself [30]–[32]. This type of comparison can improve performance by reducing anxiety [31] and increasing motivation [33].

The general impact of social comparison on well-being has largely been attributed to its close relationship with people's self-esteem and self-efficacy [34], [35]. Self-esteem relates to individuals' overall attitude toward themselves, including positive and negative self-perceptions. Self-efficacy on the other hand, refers to people's belief in their capabilities to achieve a goal or succeed in a task [36], [37]. These constructs also have trait and state aspects. Trait self-esteem represents people's stable overall confidence, while trait self-efficacy is the stable belief in one's ability to accomplish goals. The state aspect of both constructs changes based on current events and experiences [38], [39].

Engaging in upward social comparisons has been shown to result in a decline in self-esteem [23], [26], [40] as individuals feel inferior to others [21], [23], [40]–[42]. Unless the comparison target's performance is on a dimension that has little or no relevance to one's self [40], upward comparison can lead to an intense negative impact on the way people perceive themselves [43]–[45]. Conversely, balanced or downward social comparisons, where individuals compare themselves to those they perceive as equal to them or less capable, can enhance self-esteem, providing reassurance and enhancing the way people perceive themselves [31], [46], [47]. Social comparison has also been shown to impact one's self-efficacy [48]–[50]. People tend to avoid information suggesting others are outperforming them [23], but when such information cannot be avoided, it commonly triggers an experience that threatens people's confidence in their abilities [14], [23]. This negative impact on self-efficacy is believed to be even more intense when the others' performance is perceived as unachievable by them [49], [50]. When people experience downward comparison, comparing themselves to others who are perceived as inferior, they are likely to experience an increase in self-efficacy, as they perceive themselves as more competent or skilled than their comparison target(s) [47].

Being such a basic process in human nature, the tendency to compare oneself to others is likely also to be relevant when interacting with robots [17], [21], [51]. Indeed, there are already indications for social comparison in HRI [6], [14], [52]–[54]. The presence of robots in our environment introduces new aspects to this fundamental social behavior. Recent studies in the field of HRI have shown that performing a task next to a robot can trigger social comparison, either when performing a collaborative task [6], [22] or without direct collaboration [14]. The common belief that technology is superior to humans due to its computational abilities [55] commonly leads to upward comparison (i.e., perceiving the robot as capable of better and sometimes unachievable performance). The perception of robots as superior occurs even without any indication of the robot's abilities and even in cases where it demonstrates low-quality performance [14]. This tendency to overestimate robots' capabilities, combined with the tendency for social comparison, can impact people's self-esteem and self-efficacy, which are believed to be essential for people's general well-being [34], [35]. Such intense negative effects of comparison to a robot may be overlooked if people simply perform a task next to it without direct interaction. It is therefore important to test whether performing a task alongside a robot can threaten those basic psychological constructs.

This possibility is not remote as previous studies have already indicated that interactions with robots have the potential to impact both self-esteem [56]–[58] and self-efficacy [59]–[64]. Robots have the potential to enhance people's self-esteem by attending to them and increasing their inclusion in interactions, while rejection by robots typically threatens self-esteem [57], [65]. Interactions with robots can also enhance self-efficacy. Building or teaching robots have been indicated as activities that can greatly support people's belief in their own capabilities, especially when the activity is successful [66]–[68]. These indications that people's self-esteem and self-efficacy are sensitive to robots' behavior further emphasize the need to map the impact of social comparison to a robot on these fundamental psychological constructs, which are essential to maintaining stable well-being.

In this study, we tested whether performing a task alongside a robot and the associated *Upward* or *Downward* comparison would influence participants' self-esteem and self-efficacy. Participants performed a search task alongside a robotic dog that performed a similar independent task. We tested the impact of social comparison to the robot's performance in three conditions: *Upward comparison*, where the robot performed better than the participant; *Downward comparison*, where the robot performed worse than the participant; and *Equal performance*, where the robot's performance was equal to that of the participant. We evaluated whether the participants' inherent tendency to compare their performance to that of the robot would impact their self-esteem and self-efficacy.

II. Related Work

Previous related research has explored self-esteem, self-efficacy, and social comparison in human–robot interactions.

1) Self-Esteem in HRI: Several HRI studies indicated that social interactions with robots can facilitate participants' sense of self-esteem [56]–[58]. For example, Erel et al. [57] found that experiencing over-inclusion during an interaction with two robots can support participants' self-esteem. In their study, participants played a ball-tossing game with two non-humanoid robots. When the robots directed most of the tosses toward the participant (i.e., the robots tossed the ball to the participant more than they tossed to each other), higher self-esteem levels were reported compared to participants who received a similar or lower number of tosses from the robots. Similarly, Nakamura and Umemuro [58] found that older adults' self-esteem increased after they experienced a self-disclosure interaction with a robot. Participants who shared their life experiences with a NAO robot showed a constant rise in their self-esteem throughout the interaction. Other studies presented negative consequences on self-esteem after a human–robot interaction [65], [69], [70]. For example, Nash et al. [65] found that rejection by a robot can significantly impact self-esteem. A Baxter robot that informed participants that it would not like to play with them again (after playing a game of Connect-4) led to a significant decrease in self-esteem.

These studies indicated that interactions with robots can lead to either a positive or negative impact on participants' self-esteem. We extend this line of work by testing whether performing a task alongside a robot would increase or decrease participants' sense of self-esteem as a function of the robot's performance (better or worse than their performance).

2) Self-Efficacy in HRI: Several studies have evaluated the impact of robots on participants' self-efficacy [59]–[64], [71], mostly focusing on the advantages of building and teaching robots. These studies indicated that a do-it-yourself (DIY) activity of building a robot could enhance participants' sense of self-efficacy [66], [72], [73]. For example, Huang et al. [66] found that students who built a robot, while solving problems and experiencing challenges, reported higher confidence in their abilities and increased self-efficacy. Moreover, following the activity, participants demonstrated an increase in their belief that they could solve complex tasks in general. Teaching a robot was also shown to enhance self-efficacy [67], [72]. For example, participants who taught a robot how to solve math problems reported higher self-efficacy related to their math skills [67]. Similarly, Rosenthal-von der Pütten et al. [72] showed that training a robot in a cooking activity could enhance students' self-efficacy. HRI studies have also indicated that feedback from a robot can impact people's self-efficacy [62], [74], [75]. For example, Zafari et al. [68] found that robotic personal feedback during a card-tower building task enhanced participants' self-efficacy.

We extend this line of work by examining whether simply performing a task next to a robot would influence self-efficacy. We evaluated whether participants' tendency to compare their performance to the robot's can increase or decrease their perception of their own abilities.

3) Social Comparison in HRI: Several studies have examined social comparison in the context of HRI [6], [14], [52]–[54]. Most of these studies have investigated how social comparison to robots influences the perception of job insecurity. For instance, Granulo et al. [53] suggested that people see the possibility of being replaced by robots as a significant threat to their future economic opportunities. This effect was attributed to engaging in upward social comparison and viewing robots as highly skilled. Other studies demonstrated the impact of robotic feedback that involved social comparison. Allan et al. [52] found that relative robotic feedback indicating that the participant was better than other people in a knowledge quiz game, led to a higher evaluation of the robot. Similarly, when a robot coach compared post-stroke participants' performance to that of other people, they demonstrated upward comparison, which led to hesitation in task performance [62]. Another type of studies indicated that simply performing a task next to a robot can lead to social comparison. Yaar et al. [14] demonstrated that participants engage in social comparison to a robot even if there is no direct interaction with it. Participants were asked to search for symbols on cubes that were arranged in space in a way that defined a clearly efficient search pattern. Participants performed the search task alongside a robot that performed the same task and demonstrated an inefficient search pattern. They found that performing the task alongside the robot led to an upward comparison where most participants perceived the robot's performance as superior and overestimated its abilities (despite the clearly inefficient search). The upward comparison led to a decreased sense of control and decreased participants' performance accuracy.

These studies indicate that social comparison in HRI can impact individuals' experience. We extend this line of work by testing the impact of social comparison (both upward and downward comparisons) on two constructs that can highly impact humans' well-being: self-esteem and self-efficacy.

III. Method

To evaluate the impact of social comparison to a robot on self-esteem and self-efficacy, we adapted the search task presented by Yaar et al. [14]. In the search task, participants are requested to find symbols on cubes alongside a robotic dog that was introduced as performing search training in the area (see Figure 1). We compared participants' self-esteem, and self-efficacy under three conditions: (1) *Upward comparison*, (2) *Downward comparison*, and (3) *Equal performance*.

1) Search task: Based on Yaar et al. [14], participants were asked to review 10 cubes with different symbols on them and count the number of cubes marked with two different target symbols (A and B in Figure 2, Left). Participants were informed that the robotic dog was also looking for two (different) symbols (C and D in Figure 2, Left). Each of the 10 cubes had five symbols (one on each face except the bottom one). All cubes had one symbol that either the participant or the robot had to find (four cubes had symbol A, four cubes had the symbol D; one cube had symbol B and one cube had the symbol C; see corresponding symbols in Figure 2, Left). The 10 cubes were placed in a quiet outdoor environment on campus (in an area suitable for a robotic dog to search). The cubes were organized in two columns of five cubes each (introducing a clearly efficient search pattern based on the Gestalt principle of proximity). We adapted the original search task to include several changes: (1) We used two target symbols instead of one, to slightly increase participants' engagement, and asked participants to report the number of times each symbol appeared on the cubes; (2) Instead of looking for the same symbols, the participant was asked to look for different symbols than the robot. We did it to adapt the task to a scenario where both are working toward a similar goal but are engaged in different sub-tasks alongside each other (and to test if social comparison exists even if their tasks were not exactly the same and not directly comparable); (3) We added a *Downward comparison* condition to evaluate the impact of performing better than a robot; (4) We designed the robot's search pattern to follow gestalt rules (in all conditions) and therefore be a logically efficient pattern.

Fig. 2. Left - Cubes and target symbols. A & B are the participants' target symbols; C & D are the robot's target symbols. Center - The unitree Go1 quadruped robot used in the experiment. Right - Organization of the cubes and distances. Cubes with the participant's target symbols are marked in yellow.

While performing the task, the robot moved from one cube to another in an efficient path, performing scanning gestures next to each cube. The task was intentionally designed to be simple, ensuring that participants could perform it easily, to avoid a task-related threat to participants' self-esteem and self-efficacy.

A. The robot and gesture design

We used a Unitree Go1 robot (see Figure 2, Center). The Go1 is a 15 kg quadruped robot with 12 degrees of freedom. Choosing a robotic dog allowed us to use a search task relevant to both the participants and the robot. It also allowed for the design of behaviors that align with participants' familiarity with real dogs, reducing the cognitive load associated with encountering a novel robotic behavior. In all conditions, the robotic dog performed the same three gestures. Two gestures were replicated from Yaar et al. [14]: *Hello* for an appropriate opening encounter [76]; and *Scanning* indicating that the robot was scanning and searching for the symbols on a specific cube. We added a third gesture of *Reporting* to indicate how many symbols the robot had found. This gesture was designed with an animator and validated, together with the other gestures, in a pilot study to verify that participants perceived them accurately. All 15 participants easily understood the gestures. The gestures were performed as follows:

Hello: At a distance of 65 cm in front of the participant, the robot simulated nodding by moving its front part up toward the participant three times and then moving to position itself next to the participant.

Scanning: The robotic dog leaned closer to each cube by lowering its front part in front of the cube and performed right-to-left rotations of its head, simulating scanning the cube.

Reporting: At the end of the search task, the robot stood in front of the researcher and waited for a command. When asked to report the first symbol, it lowered its front part toward the ground and returned to a balanced position. When asked to report the second symbol, it repeated the same movement four times, indicating that it had found one instance of its first target symbol and four instances of its second target symbol.

B. Participants

Sixty-six undergraduate students from the university participated in the study (42 females and 24 males; mean age = 24.39 years, SD = 4.78, 22 per condition, none were excluded). The sample size was based on a G power analysis [77] with a medium-high effect size (based on previous studies, [78], [79]), three groups, and a power of 0.95. It was also supported by related studies [80]–[82]. Participants signed a consent form and received extra course credit or a 15 USD gift card. The institution's ethics committee approved the study.

C. Experimental settings

The 10 cardboard cubes were placed in two parallel columns in the outdoor environment. This organization allowed the establishment of a clear and efficient search pattern. According to the Gestalt principle of proximity [83], [84], the relative distance between objects affects our perception in a way that defines an organization of the objects into sub-groups. Hence, similar to Yaar et al. [14], the distance between the columns (4 m) was greater than the distance between the rows (2.5 m) (see Figure 2, Right). A symbol was printed on each of the cube faces, except the bottom one, meaning there was a total of five symbols on each cube. At the far end of the outdoor space, we placed two chairs and a table with a computer where the participant's experience was evaluated after performing the search task alongside the robotic dog (see section III-E).

D. Experimental design

The between-participant experimental design involved three conditions: *Upward comparison*, *Downward comparison*, and *Equal performance*. The social comparison manipulation was based on the robot's speed in performing the task – whether it completed it before the participant (*Upward comparison* condition), after the participant (*Downward comparison* condition), or at the same time as the participant (*Equal performance* condition). The impact of the robot's search time on the participants' social comparison was validated in a pilot study.

1) Pilot study: To verify that the robot's behavior in the search task would trigger social comparison and to validate the comparison direction, we designed a pilot study with 21 participants (8 females and 13 males; mean age = 24.57 years, SD = 1.83). The participants were randomly assigned to one of the three conditions. After performing the search task alongside the robot, participants' social comparison was evaluated by asking them to mark their performance relative to that of the robot on a 1–100 scale (1: "I performed better" to 100: "the robot performed better"). Our results validated the existence and direction of social comparison in the different conditions ($F = 23.2$, $p < 0.001$). In the *Upward comparison* condition, the participants rated their performance as inferior to the robot's performance (mean - 72.4). In the

Downward comparison condition, the participants rated their performance as superior to the robot's (mean - 25.8), and in the *Equal performance* condition, the participants rated their performance as equal to the robot's (mean - 50.8).

2) Experimental conditions: Based on the pilot study, we designed three conditions for the main study (i.e., for evaluating the impact of a social comparison to a robot on self-esteem and self-efficacy). The only difference between the conditions was the time required for the robot to complete the task (relative to the participant). In the *Upward comparison* condition, the robot scanned the cubes faster than the participants and finished before them. In the *Downward comparison* condition, the search path of the robot was similar, but it performed the search task slower than the participants (it performed the *Scanning* gesture next to each cube more slowly) and finished after the participants. In both conditions, the robot performed an effective search, beginning in one column (according to the participant's path) and continuing to the other. In the *Equal performance* condition, the robot performed the search alongside the participant but in a mirror image (if the participant started their search from the first cube on the right column, the robot started from the first cube on the left column, and vice versa) and finished the task at the same time. Once both had completed the task and arrived back at the starting point, the researcher determined the reporting order by the order in which they finished the task: In the *Upward comparison* condition, the robot reported first; in the *Downward comparison* condition, the participant reported first; and in the *Equal performance* condition, the reporting order was counterbalanced. Participants were randomly assigned to the conditions using a matching technique that balanced gender, Self-Esteem (trait) [85], Self-Efficacy (trait) [86], Social Comparison Orientation (SCO - tendency to perceive oneself as inferior or superior to others) [87], and Negative Attitudes Toward Robots (NARS) [88][1].

E. Measures

We assessed the impact of performing a task next to a robot on participants' self-esteem, self-efficacy, and performance using quantitative and qualitative measures.

1) Self-esteem: To measure the robot's impact on participants' self-esteem, we used the State Self-Esteem scale (SSES)[2] [89]. This questionnaire was designed to evaluate participants' self-esteem in a specific context. We used the two sub-scales relevant to the experiment's context: the performance sub-scale and the social sub-scale (Alpha Cronbach = .87, .89). The participants were asked to answer 10 questions on a 5-item Likert scale (1: "not at all" to 5: "extremely").

2) Self-efficacy: To evaluate the robot's impact on participants' self-efficacy, we used the Lexical Decision task (LD) [90]. This measure allows for an evaluation of situational self efficacy (unlike questionnaires that typically test trait self-efficacy [63] or task-specific self-efficacy (e.g., efficacy in math: [67]; efficacy in operating robots: [73]). The LD is a general tool for assessing specific aspects of participants' experiences. It is a reaction-time (RT) measure that evaluates immediate experiences in different contexts [91], [92]. The LD task has been previously used to measure participants' sensitivity to different contexts based on their recent experiences [93], [94] including self-esteem [95], stereotypical thinking [96], attachment [97] and self-efficacy in HRI [98]. Previous research has indicated that reaction times to emotionally charged words, particularly negative ones, are influenced by both the emotional context and the relevance of the stimuli to the participant's current situation. Individuals tend to react more slowly to negative words when they are contextually irrelevant, likely due to an inherent defense mechanism [91], [99]. However, when the emotional context is relevant, such as processing negative words after a negative event, reaction times to negative words align more closely with those to neutral words [91]. This change in RTs is explained by context-related arousal, meaning people respond faster to words that reflect their current emotions related to their recent experiences [100]. In the task, participants were asked to classify, as quickly as possible, strings of letters as either a word (e.g., "tree") or a non-word (e.g., "erte") by pressing 'P' on the keyboard for words or 'Q' for non-words. Out of the 28 strings used in the task, 14 were words, and 14 were nonwords. Out of the 14 words, 7 words were associated with feelings of self-inefficacy (e.g., difficulty, problem), and the other 7 were neutral words used as control stimuli (e.g., door, closet). We measured RTs to evaluate participants' self-inefficacy. We hypothesized slower RTs to inefficacy words compared to the neutral words in the *Downward comparison* and the *Equal performance* conditions, as inefficacy was not relevant for the participants' recent experience in the search task, and they could activate appropriate defense mechanisms. However, we predicted that in the *Upward comparison* condition, inefficacy would become relevant to the participants' recent experience, and therefore, their RTs to inefficacy words would become similar to their RTs to neutral words.

3) Performance measures: While not the paper's primary focus, we also evaluated participants' performance by assessing their: (1) Accuracy (i.e., four cubes with the first symbol and one cube with the second symbol) and (2) Search time.

4) Manipulation check: To further verify the experience of social comparison under the different conditions, we introduced the relative performance question that was used in the pilot study and asked participants to rate their performance in relation to the robot's on a 1–100 scale (1: "I performed better" to 100: "the robot performed better").

5) Robotic Social Attributes Scale (RoSAS): We additionally tested the perception of the robot using the RoSAS questionnaire. The 9-point Likert scale (1-"low", 9-"high") evaluates the perception of the robot's warmth, competence, and discomfort [101]. Alpha Cronbach for the three sub-scales: Warmth = .79, Competence = .82, Discomfort = .80.

6) Qualitative measure – semi-structured interview: Finally, we conducted a semi-structured interview to understand

[1]Link to the pre-test questionnaires used in the study.

[2]Link to the SSES questionnaire used in the study.

the participants' experience [102]. The interview was designed to evaluate their overall experience, thoughts about the task performance, and thoughts about the robot (e.g., "Describe your experience?"; "What did you think of the robot?").

F. Procedure

A few days before their arrival, participants received the pre-test questionnaires by email Self-Esteem (trait) [85], Self-Efficacy (trait) [86], SCO [87], NARS [88], and a demographic questionnaire). Once the participants arrived at the lab, they signed a consent form and were invited to the outdoor space. There, they received the instructions for the search task, while the robotic dog was not visible to them. The researcher explained that a robotic dog was performing search training in the area, so it may perform a similar search task alongside them while searching for different symbols. They were also informed that they needed to perform the task in the most efficient way. The researcher showed the participants all the symbols that may appear on the cubes and requested them to find their target symbols. The researcher also indicated the two symbols the robot was required to find, verifying that they understand that the robot was not performing the exact same task as they were. The researcher then took the participant to the starting point, and the robotic dog approached them and performed the *Hello* gesture, to follow acceptable social norms and avoid the perception of the robot as ignoring them (see [76]). The researcher asked the participant to plan the search patterns and to begin searching. The participant then performed the search task alongside the robotic dog. The robot's behavior and performance were determined based on the relevant condition. The robot was controlled remotely, using a "Wizard-of-Oz" technique by another researcher who was not visible to the participants [103], [104]. After completing the search, both the participant and the robot were asked to report the number of each target symbol. Finally, the researcher asked the participants to sit next to a table where they completed the LD task and questionnaires, participated in an interview, and confirmed that the robot was perceived as fully autonomous and that the overall experience was positive.

IV. Analysis

To verify the lack of early differences between the conditions, we conducted Bayesian analyses for all pre-tests (as it allows for testing NULL hypotheses). To verify that the robotic conditions led to social comparison and to analyze the robot's impact on participants' self-esteem, performance, and RoSAS we conducted one-way ANOVA analyses. To evaluate the robot's impact on self-efficacy, we analyzed the LD reaction times using a two-way ANOVA that tested the interaction between the robotic condition (*Upward comparison* vs. *Downward comparison* vs. *Equal performance*) and the word type (*inefficacy* vs. *neutral*). The interviews were analyzed using thematic coding [102]: (1) Two coders transcribed the interviews; (2) Initial themes were extracted from the data; (3) The themes were discussed with a third researcher, and any inconsistencies were resolved; (4) Two coders analyzed 30%

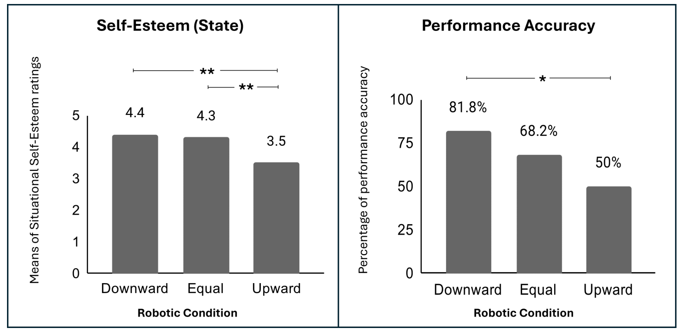

Fig. 3. Self-esteem ratings (Left); Performance accuracy (Right).

of the interviews independently to verify inter-rater reliability (kappa = 85%); (5) The rest of the interviews were coded.

V. Findings

The Bayesian analysis indicated no early differences between the groups: (Self-Esteem trait $BF_{10} = 0.29$ ($F_{(2,63)} = 0.1$, $p < 0.87$); Self-Efficacy trait $BF_{10} = 0.06$ ($F_{(2,63)} = 0.02$, $p < 0.95$); SCO $BF_{10} = 0.3$ (($F_{(2,63)} = 0.12$, $p < 0.81$)), and NARS $BF_{10} = 0.15$ ($F_{(2,63)} = 0.05$, $p < 0.89$). The manipulation check analysis revealed that the robot's relative performance led to social comparison. When asked to rate their performance in relation to the robot's (1: "I performed better" to 100: "the robot performed better"), the participants provided different ratings based on the robotic condition, $F_{(2,63)} = 48.70$, $p < 0.001$. In the *Downward comparison* conditions, the participants rated their performance as better than the robot's (mean = 29.10, SD = 15.68); In the *Equal performance* condition, the participants rated their performance as equal to the robot's (mean = 54.62, SD = 15.38); In the *Upward comparison* condition, the participants rated their performance as worse than the robot's (mean = 78.36, SD = 18.42). All Scheffe post-hoc comparisons were significant (*Downward comparison* vs. *Equal performance* conditions: $p < 0.001$; *Downward comparison* vs. *Upward comparison* conditions: $p < 0.001$; *Upward comparison* vs. *Equal performance* conditions: $p < 0.001$).

A. Self-Esteem

The one-way ANOVA analysis indicated that the social comparison to the robotic dog impacted participants self-esteem ratings, $F_{(2,63)} = 14.23$, $p < 0.001$, $\eta_p^2 = 0.31$ (see Figure 3, Left). Post-hoc Scheffe analyses indicated that the participants in the *Downward comparison* condition and in the *Equal performance* condition reported higher self-esteem than participants in the *Upward comparison* condition ($p < 0.001$, $p < 0.001$). The difference between the *Downward comparison* and *Equal performance* conditions was not significant.

B. Self-Efficacy

The two-way mixed ANOVA that included the robotic conditions and word type (inefficacy vs. neutral words) revealed a significant interaction, $F_{(2,63)} = 3.15$, $p = 0.049$, $\eta_p^2 = 0.13$ (see Fig. 4). Post-hoc Scheffe analyses indicated that in

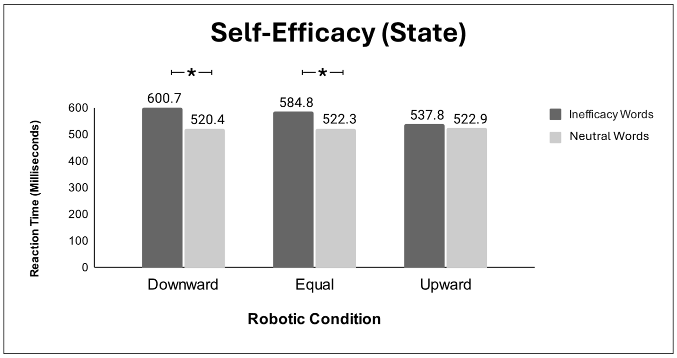

Fig. 4. Analysis of the LD reaction times across conditions and word types.

the *Downward comparison* condition and in the *Equal performance* condition, the participants responded significantly slower to inefficacy words than to neutral words (p = 0.007; p = 0.05). However, in the *Upward comparison* condition, the reaction times to the different word types were almost equal. Indicating that under this condition the inefficacy words were relevant to participants' recent experience. The word type main effect was significant, $F_{(2,63)} = 22.9$, $p < 0.001$, $\eta_p^2 = 0.13$. The main effect of the robotic conditions was not significant.

C. Performance - accuracy and time

The one-way ANOVA analysis of participants' performance accuracy indicated that the social comparison to the robotic dog impacted participants' performance accuracy, $F_{(2,63)} = 3.01$, $p = 0.05$, $\eta_p^2 = 0.1$ (see Figure 3, Right). Post-hoc Scheffe analyses indicated that performance accuracy in the *Downward comparison* condition was higher than in the *Upward comparison* condition (p = 0.048). The other comparisons were not significant. The analysis of the time required to complete the task revealed no significant differences.

D. Robotic Social Attributes Scale (RoSAS)

The RoSAS analysis revealed no significant effects.

E. Qualitative measure – semi-structured interview

The analysis revealed two main themes: (1) Social comparison and perception of performance; (2) Participants' feelings during the task.

1) Social comparison and perception of performance: Most participants across conditions compared their performance to the robot's, perceiving it as better, worse, or equal. In the **Upward comparison** condition, most (14/22) felt outperformed by the robot in speed and accuracy, often highlighting its technical advantages (*"It was quicker; it can move faster than me."* (p. 32, F)) and feeling that the robot's capabilities were beyond their reach (*"It is a robot, it is always accurate and I am not... it was more effective."* (p. 8, F)). This led many of them (8/14) to describe negative feelings and low self-efficacy (*"I felt slow and didn't remember the symbols well, maybe there was a method that I didn't think of."* (p. 47, F)). In the **Downward comparison** condition, most (15/22) reported having superior performance: *"I think I did better than the robot, I have an advantage in terms of size."* (p. 46, F). Almost all (12/15) described their performance positively and potentially better than other humans, emphasizing high self-efficacy: *"I think I was efficient, I'm better than average in performing such tasks."* (p. 60, M). In the **Equal performance** condition, most (13/22) felt they matched the robot's performance, often describing a sense of partnership and synchronization: *"We finished at the same time, I think we are relatively equal."* (p. 39, F). Most of them (10/13) expressed satisfaction with their abilities: *"I think I was focused, I probably was more accurate."* (p. 64, F).

2) Participants' feelings during the task: A total of 43/66 participants also mentioned how they felt during the task and how the robot's presence affected their actions and feelings. In the **Upward comparison** condition, 18/22 participants discussed their feelings, most of them describing negative feelings (14/18), including low self-esteem, stress, and frustration: *"The robot made me question myself, something in its presence..."* (p. 59, F). The participants also discussed feeling a sense of competition with the robot that led to anxiety: *"It was very fast and it stressed me out. I had to compete with it."* (p.53, F). Only 4/18 participants described positive feelings, mentioning the drive to do better than the robot *"It gave me a push, a motivation to win."* (p.2, F). In the **Downward comparison** condition, out of the 13/22 participants who mentioned their feelings, most participants reported positive feelings (10/13), including increased confidence and positive self-esteem: *"I think the robot's presence raised my confidence, I was quicker and I felt good about it."* (p.58, F). Only 3/13 participants described negative feelings: *"I think it was trying to let me win."* (p.61, M). In the **Equal Performance** condition, 12/22 participants described both positive and negative experiences. 7/12 mentioned positive feelings and discussed being motivated: *"I think I performed well because I didn't have the element of pressure, only the element of competition."* (p.42, F). 5/12 participants described negative feelings: *"I was distracted by the robot."* (p.12, F).

VI. Discussion

In this study, we showed how performing a task alongside a robot can impact basic psychological constructs that are at the core of human well-being. Despite the lack of direct interaction with the robot (apart from a short greeting, see [76]), its performance (of an independent task) led to an intense impact on participants' self-esteem and self-efficacy. Participants automatically engaged in social comparison and estimated their performance and capabilities relative to those of the robot. When the robot performed better than them (*Upward comparison* condition), they experienced a significant decrease in both self-esteem and self-efficacy. Moreover, despite the simple nature of the task, the comparison to the robot impaired their performance and resulted in inaccurate reports of the number of symbols they were asked to find. Such intense impact related to merely being in the presence of a robot that is performing a (somewhat similar but independent) task, was also indicated by participants' descriptions in the interview of *"lagging behind it"* or *"running after the robot,"* which made them *"feel frustrated"* and *"question"* their capabilities.

Our findings suggest that similar to other basic social effects in human psychology, social comparison is another effect humans apply to their interactions with robots. Similarly to interactions between humans, interaction with a robot also automatically triggers social comparison and the direction of that comparison heavily impacts the human's self-perception (possibly altering their social value [105]). Despite the robot's mechanical nature, participants found it a valid agent for comparison and could not avoid the negative impact on their self-esteem and self-efficacy. This highlights humans' strong tendency to perceive robots as social entities [51], even without experiencing any social interaction with them, but rather simply performing a task alongside them.

Interestingly, the results of the social comparison observed in our study were only partially similar to the effects observed when people compare themselves to other humans. While the *Upward comparison* resulted in a clear threat to self-esteem and self-efficacy as is commonly observed in human interactions, *Downward comparison* did not improve participants' self-esteem, self-efficacy, or performance (in comparison to *Equal performance*), which is the common finding in human interactions [46], [47]. These findings align with the Robot Social Influence (RoSI) model [106], which highlights expectations as one of the factors shaping robots' social influence. It is possible that participants' expectation that a robot would have a better performance due to overestimation of robots' capabilities [107], [108] led to a similar effect in the *Downward comparison* and *Equal performance*. Since the robot violated participants' expectations in both conditions, their self-esteem and self-efficacy improved, and thus, no differences were found between the groups. More generally, our results suggest that social comparison and similar psychological constructs (e.g., mere presence effect) should be updated and adjusted in an era that presents new social entities.

It is possible that the lack of difference between the comparison to a robot that performed worse than the participant, and a robot that performed equal to the participant, was related to the participants' a priori expectations that a robot would outperform them. In this case, participants who performed equally to the robot already perceived themselves as demonstrating high capabilities, since their performance matched that of a robot, which they believed had superior abilities. This may have enhanced their self-esteem and self-efficacy in a similar way to a comparison to a robot that they outperformed. Interestingly, participants did not report any discomfort in the *Equal performance* condition, although the robot performed the task in a mirror image. Instead, they expressed surprise when the robot's performance was not superior: *"I thought it would be better than me."* When the robot did not fulfill these expectations, participants' self-esteem and self-efficacy improved because their performance matched or exceeded that of an advanced robot. This explanation suggests that it is possible to leverage the presence of robots to empower people. The potential to facilitate people's self-esteem and self-efficacy by simply designing robotic performance that matches that of the humans in its environment should be further explored as it presents an opportunity to easily enhance humans' well-being.

Taken together, our findings indicate the great importance of carefully designing robotic behaviors even when the robots concerned do not directly interact with the humans around them. Our findings suggest that failing to consider the impact of a robot that performs tasks in the presence of people may have profound effects as it is likely to impact basic psychological constructs that contribute strongly to humans' well-being. As we enter an age where robots perform tasks alongside humans and share their environment, it's important to carefully choose the tasks they perform and the performance they exhibit next to humans who perform tasks alongside them. Focusing only on their efficiency can result in highly negative implications that could either lead to rejection of the robot or, more importantly, decrease the self-esteem and self-efficacy of the people who work next to them.

VII. Limitations

The study has several limitations. First, the robot used in the study has a specific morphology with limited social expressivity and is perceived as a mechanically complex advanced robot. It is possible that the social comparison to a simpler robot, or on the other hand to a robot capable of more complex social and psychological behaviors, would lead to different effects (although people tend to overestimate the capabilities of very simple robots [107], [109]). Additional limitations concern the specific use of an artificial search task. Future studies should test the impact of social comparison to a robot in field studies with tasks that have more meaningful consequences (risks or gains) and capture real-life complexity. It is also important for future research to evaluate whether the task complexity and its similarity to the task performed by the participants mediated the social comparison effects. Finally, interviews might be influenced by the interviewers' expectations and the "good subject effect" [110], [111].

VIII. Conclusion

Our work highlights the importance of considering people's tendency to social comparison when designing environments shared by humans and robots. Robot designers should be aware and carefully consider the possibility that people would compare themselves and their performance to that of robots they do not directly interact with. Such comparison may lead to an intense impact on their basic psychological constructs, including their self-esteem and self-efficacy. The importance of these psychological constructs to people's well-being suggests that overlooking possible *Upward comparisons* when designing HRIs may result in general negative effects on humans in the robots' environment.

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