ROBOT CONTROL

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As robots become common in our everyday lives, they are predicted to perform tasks alongside humans. Social psychology studies
indicate that performing tasks next to others leads to a social comparison. The tendency to overestimate robots’ capabilities is predicted
to lead to an upward comparison that can result in negative outcomes. We evaluated whether performing a task alongside a robot
would impact participants’ sense of control and their overall performance. Participants performed a simple search task either before or
alongside a robotic dog that was presented as performing search training. Our findings indicated that performing the task alongside
the robot led to a negative impact on sense of control, search efficiency, and performance accuracy. We conclude that robot designers
should carefully consider the impact of robots who perform tasks alongside humans, even when the interaction does not involve
collaboration and despite the independence between the human and the robot’s performance.

CCS Concepts: - **Human-centered computing —> Empirical studies in HCI.**

Additional Key Words and Phrases: Opening encounters, Greeting, Help request, Human-Robot Interaction, Robot, Interaction quality

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1. INTRODUCTION

Robots are predicted to become an integral part of our everyday lives, share our environment, and perform tasks
commonly performed by humans [33, 38, 50], In this context, it is believed that one of the near future challenges
concerns the development of a cohesive workforce that involves humans and robots working alongside each other
[33, 50], Performing tasks alongside robots presents several challenges related to the nature of the interaction, the
robot’s behavior, the workers’ attitudes, and the task features [4, 26, 33, 50], Various studies have explored factors
that enhance collaboration with robots (e.g., the level of the robot’s autonomy [8], trust [4], and sense of safety [50]).
However, working alongside a robot may also involve simply sharing the same space while performing a task without
direct collaboration (e.g., [28], [44]). Such interactions are likely to become common as robots are perceived as means
for sharing workload [24] and for performing less desirable aspects of tasks performed by humans [33]. It is, therefore,
surprising that the impact of performing a task alongside a robot (without direct collaboration) is hardly studied.

Studies from the social psychology domain consistently indicated that performance in the presence of others is not
similar to individual performance [5,14, 49, 53]. Specifically, it is suggested that there are drastic effects to performing a
task alongside others who perform similar tasks [14,40,49]. In these cases, people typically engage in social comparison
due to an inherent tendency to observe others’ performance and judge their own performance accordingly [14]. When
people compare themselves to those who outperform them (upward comparison), they commonly report a negative
experience. A downward comparison (comparison to those who under-perform) commonly leads to a positive experience
[14, 49]. Such social comparisons have been shown to impact several factors, including one’s sense of control [5, 43]
and performance quality [27]. In particular, it is indicated that upward comparison leads people to reconsider their

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Fig. 1. Robotic dog and participant.

own abilities. This, in turn, negatively impacts their performance due to attentional resources captured by ruminative
thoughts about their under-performance [27]. Questioning the capability to perform the task and the accompanying
decrease in performance have additional negative effects, including a decrease in sense of control [14, 40, 49].

Maintaining a sense of control in human-robot interaction was indicated as a key factor for robot acceptance [1,8],
positive perception of the robot [54], and the general quality of the interaction [1], It is known to impact various
important factors that shape the interactions, including people’s level of trust in the robot [3], sense of safety [1],
perception of teamwork with the robot [54], and sense of authority [18]. The indication that maintaining a sense of
control can be compromised by performing tasks alongside others suggests that performing a task next to a robot could
have negative results. This possibility is especially alarming when considering people’s tendency to perceive robots as
having superior abilities and skills [11, 37, 41]. Such overestimation of a robot’s capabilities may lead to an upward
comparison that would result in a decrease in people’s sense of control and overall performance.

In this work, we explored this possibility and tested if performing a task alongside a robot would impact participants’
sense of control and the quality of their task performance. We evaluated if simply performing a task next to the robot,
without direct collaboration, would have a negative impact despite the complete independence between the participant’s
performance and the robot’s performance. To evaluate the extent of such impact, we intentionally designed a very simple
task (i.e., that does not involve a-priori control challenges) and informed participants that the robot was being trained to
perform the task (i.e., giving them no reason to believe that the robot has superior capabilities). Participants performed
a search task where they were asked to find "X" symbols on cubes (see Figure 1). We compared their performance and
sense of control in two conditions: (1) performing the task alongside a robotic dog; (2) performing the task alone.

1. RELATED WORK

Relevant previous work includes studies that evaluated robots’ impact on participants’ sense of control, Overestimation
of robots’ capabilities, and social comparison in human-robot interaction.

* 1. Sense of Control

Several studies evaluated participants’ sense of control in human-robot interactions [25, 52]. Most of these studies
explored whether control over the robot’s actions would impact participants’ general sense of control and robot
acceptance [8, 9, 52, 54, 55]. For example, Chateau et al. (2016) manipulated the control over a robot during a cleaning
task. They used two robots and manipulated the participants’ control over the "manager" robot, who either asked them
to activate the "cleaning" robot, asked for their permission to activate the "cleaning" robot, or activated the "cleaning"robot without permission. Their findings showed that the participants’ level of control decreased as the autonomy of
the "manager" robot increased [8], Negative interactions with robots were also shown to impact participants’ sense of
control [12, 47, 51]. Erel et al. (2021) found that experiencing exclusion during an interaction with robots can threaten
participants’ sense of control. Participants who played a ball-tossing game with two robots and hardly received the
ball reported lower levels of control [12]. The sense of control was also altered by performing a joint task with a robot.
Ciardo et al. (2018) asked participants to inflate a balloon without exploding it. They showed that that when a robot
joined the task and could stop the balloon inflation, participants reported a lower sense of agency and control [10].

These studies indicate that interactions with robots can impact participants’ sense of control. We extend this line of
work by evaluating whether simply performing a task next to a robot would decrease participants’ sense of control.

* 1. Overestimation of robots’ capabilities

Several studies have explored the overestimation of robots’ capabilities. These studies indicate that people tend to
over-trust robots and mindlessly rely on robots’ judgment [2, 21, 36, 37]. For example, Robinette et al. (2016), showed
that people would follow a robot’s directions during an emergency evacuation scenario even when it led them in a
direction opposite to a safe exit (which was clearly marked by large emergency signs) and despite its poor performance
in a prior interaction [37]. Similarly, Karli et al. (2023) demonstrated that participants would follow a robot’s guidance
when cooking even when its instructions deviated from the written recipe they were asked to follow [19]. Another
example was presented by Salem et al. (2015), who showed that participants would comply with a robot’s nontraditional
requests (e.g., pouring orange juice on a plant) even after watching it perform errors earlier in the interaction [39].

These studies indicate the tendency to overestimate robots’ capabilities and judgment. Such overestimation leads
participants to question their own abilities [16]. In this context, performing a task alongside a robot is predicted to
trigger an upward comparison, leading to negative outcomes.

* 1. Social comparison in human-robot interactions

A few studies explored the effects of social comparison in HRI [17, 23, 46]. Most of these studies focused on the impact
of social comparison on the perception of job insecurity. For example, Wang et al. (2023) showed participants pictures
of a human working with a robot. They found that higher levels of a robot’s anthropomorphism led to engagement in
social comparison that contributed to the fear of being replaced by a robot (i.e., job insecurity) [46]. Similarly, Granulo
et al. (2019) indicated that people perceive robotic replacement as a great threat to their future economic prospects.
They attributed this effect to the perception of robots as highly capable and an upward social comparison [17].

These studies indicated that considering robots as replacements may trigger social comparison and impact the robot’s
perception. We further explore the impact of an upward comparison due to performing a task alongside a robot.

1. METHOD

We evaluated the impact of performing a task alongside a robot on participants’ sense of control by assessing their
performance and experience in a simple search task that involved identifying symbols on cubes (see Figure 1). Participants
performed the task either next to a robotic dog that also searched for symbols or before the robotic dog began to search.

* 1. The search task and the robot
		1. *The search task.* In the search task, participants were asked to review 10 cubes with different symbols on them
		and count the number of cubes with an "X" symbol. Each of the 10 cubes had 5 symbols. On four of the cubes, one of



Fig. 3. Unitree Go1 robot.

the symbols was an "X" (see Figure 2). We intentionally designed a simple task where participants would experience a
high sense of control due to their high competence and feeling that they can easily perform it accurately [34]. The
10 cubes were placed in a quiet outdoor environment on campus (in an area that would be relevant for a robotic dog
to search). To establish a clear and efficient search pattern, we organized the cubes based on the Gestalt principle of
Proximity [45, 48]. According to the Proximity principle, relative distance between objects affects our perception in a
way that would define an organization of the objects into subgroups. We, therefore organized the cubes in two parallel
columns, with 5 cubes each. The distance between the columns (4 meters) was greater than the distance between the
rows (2.5 meters), making each column a subgroup according to the Proximity principle (see Figure 4, Right). This
way, we verified that the most efficient search path (beginning with one column and then moving to the other) was
understandable. We validated the consistency of the search pattern and the simplicity of the task in a pilot study with
10 participants. All participants first searched the cubes in one column and then switched to searching the cubes in the
other (see Figure 4, Left). All participants easily and accurately reported finding four "X" symbols.

1. *The robot and gestures design.* We used a Unitree Gol robot (see Figure 3). The Gol is a small-scale 15 kg robot
with 12 degrees of freedom. The specific choice of a robotic dog allowed us to design a task (searching) that would be
perceived as relevant for both the participant and the robot. In addition, we could design a robotic behavior that would
be compatible with participants’ existing experiences (with real dogs) and reduce the need for learning processes related
to the novel context of human-robot interaction. The robot was controlled wirelessly from within the building using a
Wizard-of-Oz technique (i.e., the research assistant who controlled the robot was not visible to the participant; [29, 35]).

We designed three types of gestures: *Hello* for establishing a positive opening encounter [13]; *Scanning* for indicating
that the robot is searching for the "X"; *Excited* for indicating that the robot found an "X". The gestures were designed via
several iterations with an animator focusing on real dog gestures and indicating that the robot is performing the task.
The understanding of these gestures was validated in a pilot study with eight participants who were asked to explain
the meaning of the gestures (presented in a counterbalanced order). All participants easily understood the gestures.



Fig. 4. Cubes and search pattern

1. *Hello:* When the robot reached a distance of 65 cm from the participant, it turned its front part up towards the
participant three times (simulating nodding). The robot then stood next to the participant.
2. *Scanning:* The robot went towards each box and leaned towards it (front part lowered towards the box); it then
performed right-left rotations of its head, simulating scanning the symbols on the box.
3. *Excited:* Next to the four cubes that had an "X" symbol, the robot first performed the *Scanning* gestures and
then performed quick right-left rotations of its body (a radian angle of 90 degrees, three times in a row).
	1. Participants

30 undergraduate students from the university participated in the study (20 women and 10 men; mean age - 22.9, SD -
2.2). All participants signed a consent form and received extra course credit points or a 15 USD gift card.

* 1. Experimental Design

Our between-participant experimental design included two conditions. (1) *Alongside the robot:* participants performed
the search task in parallel to the robot. The robot began to search a few seconds before the participant to verify that
the participant noticed it. It searched the cubes in a fixed inefficient path that was not compatible with the Gestalt
principle of Proximity (see Figure 4, Center). The robot’s search behavior included moving from one box to the other,
performing the *Scanning* gesture next to each box, and the *Excited* gesture next to cubes with an "X" symbol. The
robot’s search lasted 80 seconds. (2) *Baseline:* participants were informed that the robot would perform the search task
after them. Once participants were done searching, the robot performed the exact same searching behavior as in the
experimental condition but without the participant who was waiting at the starting point. The inclusion of the robot in
the *Baseline* condition allowed us to control for novelty effects related to interacting with a robot. Participants were
*randomly* assigned to one of the conditions using a matching technique that balanced gender, negative attitudes toward
robots (NARS) [31], and *Sense of Control (trait)* [22] (to avoid a-priori differences between groups).

* 1. Dependent Measures

We assessed the impact of performing a task next to a robot using objective and subjective measures.

1. *Situational Sense of Control questionnaire:* The questionnaire is designed to evaluate participants’ sense of control
in a specific context. It is a 5-item Likert scale (l“Totally disagree” to 5 “Totally agree”) [42]
2. *Performance measures:* We used two measures: (1) accuracy - reporting four cubes with "X" symbols; and (2)
participants’ search path - whether it was (or wasn’t) efficient based on the distances between the cubes.
3. *Robotic Social Attributes Scale (RoSAS):* The questionnaire is an 18-item Likert scale assessing warmth, compe-
tence, or discomfort (l“Definitely Not Associated” to 9 “Definitely Associated”) [7],
4. *Semi-structured interview.* To understand participants’ experience, we conducted a post-experience semi-
structured interview [15, 20]. The interview included questions such as “Describe your experience,” “Describe
how you decided on your searching path,” “Describe your thoughts about the robot,”.
	1. Procedure

A few days before the experiment, participants received pre-test questionnaires by email: Negative Attitudes Towards
Robots questionnaire [31], Sense of Control (trait) questionnaire [22], and a demographic questionnaire. When par-
ticipants arrived at the experiment, they were informed that everything was recorded and that they could quit theexperiment without consequences. Participants were then invited to the outdoor space. The robotic dog was positioned
in a hidden place next to box number 9. The researcher explained that their task is to look for "X" symbol on the cubes
in the most accurate and efficient way. It was also mentioned that there is a robotic dog who is performing search
training in the same area and that it may perform the same search task. As participants reached the starting point,
the robotic dog approached them and performed the *Hello* gesture. Participants were then asked to plan their search
pattern and to begin when instructed to. They then performed the task based on the experimental condition (before or
alongside the robotic dog). After completing the search, participants were asked to report the number of "X" symbols
they found on the cubes and to take a seat on one of two chairs placed at the far end of the outdoor space. Participants
completed the situational sense of control and RoSAS questionnaires and participated in a semi-structured interview.
At the end of the experiment, the researcher verified that the participants believed that the robot was autonomous,
debriefed the participants, and verified that they left with an overall positive experience.

1. FINDINGS

To further verify the lack of early differences between groups, we first conducted Bayesian analyses for the pre-tests.
The analysis indicated no early differences between groups (NARS: *BF\q =* 0.30; Sense of control (trait): *BF\q =* 0.29).
The quantitative and qualitative main analyses indicated an impact of performing the task alongside the robot on
participants’ sense of control and performance.

* 1. Situational sense of control

A one-way ANOVA revealed that performing the task next to the robot had a significant influence on the ratings of
the situational sense of control. In the *Alongside the robot* condition, participants reported a lower sense of control
compared to the *Baseline* condition -F(i528) - 14.64, p < 0.001, *rj? =* 0.36. (see Figure 5).

* 1. Performance

The chi-square analyses of both the accuracy and search path measures revealed that the robot had a significant
influence on the participants’ performance. The accuracy analysis revealed that while in the (Baseline) condition,
almost all participants reported the accurate number of "X" symbols, in the *Alongside the robot* condition, about half of
the participants, could not provide the accurate answer /2(2) = 3.9, p < 0.04 (see Table 1). Similarly, the search path
analysis indicated that in the *Baseline* condition, almost all participants chose the efficient search path. However, in the

5 4.38



Alongside the robot Baseline

Fig. 5. Analysis of the situational sense of control.

*Alongside the robot* condition, about a third of the participants chose an inefficient path where they moved both within
and between columns inconsistently *x\z)* = 4.6, *p* < 0.03 (see Table 2).

| **Robot Condition** | **Performance Accuracy** | **Total** |
| --- | --- | --- |
| **Accuracy** | **Inaccuracy** |
| **Alongside the Robot** | 8 | 7 | 15 |
| **Baseline** | 13 | 2 | 15 |
| **Total** | 21 | 9 | 30 |

Table!. Performance Accuracy

| **Robot Condition** | **Search Pattern** | **Total** |
| --- | --- | --- |
| **Efficient** | **Inefficient** |
| **Alongside the Robot** | 9 | 6 | 15 |
| **Baseline** | 14 | 1 | 15 |
| **Total** | 23 | 7 | 30 |

Table 2. Search Pattern

* 1. Robot Perception

A one-way ANOVA analysis was performed for each of the three sub-scales of the RoSAS questionnaire. The analysis
indicated no significant differences between the different conditions for any of the scales: Warmth: F(228) = Old, *p -*0.66; Competence: f(2,28) = 2.4, *p* - 0.13); Discomfort: f(2,28) = 1-6, *P* - 0.26).

* 1. Thematic Analysis of the Semi-Structured Interviews

The interviews were analyzed using a thematic coding methodology [6]: Interview transcriptions were read several times;
Initial themes were extracted by two coders and discussed in depth with a third researcher to resolve inconsistencies;
The coders used the themes to independently analyze part of the data, verifying inter-rater reliability (kappa=83%);
The coders analyzed the rest of the data. The thematic analysis revealed three main themes: (1) Sense of control and
performance, (2) validation of social comparison, and (3) validation of overestimation of the robot’s capabilities.

4.4.7 *Theme* 7 - *Sense of control and performance.*

1. *Theme 2 - validation of social comparison.*
2. *Theme 3 - validation of overestimation of the robot’s capabilities.*
3. DISCUSSION
4. LIMITATIONS

This study has several limitations. First, we used a robotic dog with a particular morphology and specific behavior. It is
important to test further the effect of performing tasks in a robot’s presence with different robots showing different
capabilities. It is also important to test the impact of the task complexity. We chose a very simple task. It is possible that
increasing task complexity would increase or decrease the impact of the robot’s presence. The number of participants
in each group is another limitation, and future work should replicate our study with a larger sample. Lastly, interviews
may be biased by the ‘good subject effect” [30, 32], We minimized this risk by following a strict protocol that defined
the general questions, used neutral language, and emphasized that all answers were helpful.

1. CONCLUSION

We demonstrate that performing a task alongside a robot can lead to a negative impact on people’s performance and a
sense of control. The tendency to engage in social comparison was replicated in the HRI context, which involved an
upward comparison due to the overestimation of the robot’s capabilities. Our findings suggest that the impact of social
comparison should be carefully accounted for in any environment where robots and humans work alongside each other.

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