Raising Stars: Influences of Robotic Peer Liking on Emergent Leadership

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***Abstract*—Emergent leadership in teams is known as a special type of informal leadership that has unique benefits. Given that this form of leadership can be developed only organically from within the team, an informal leader may not emerge and the associated advantages can be missed. We explored the possibility of leveraging robotic social behavior to facilitate the emergence of leadership in a team. We evaluated whether a robot displaying explicit peer liking towards a specific team member would encourage that team member to take the lead. Two (stranger) participants were asked to engage in a search task together with a robotic dog who either presented peer-liking behavior toward one or both of them during the opening encounter. Our findings suggest that the robot's peer liking led the "Liked" participant to report higher sense of leadership and higher sense of responsibility over the task. Behavioral measures also indicated that the "Liked" participant managed the team's performance. We suggest that integrating a robot into human teams presents an opportunity to facilitate unique dynamics that would not develop when imposing a structure on the team from the outside.**

***Index Terms*—Interaction shaping robots; Emergent Leadership; Opening Encounters; Peer Liking; Informal Leadership**

I. Introduction

In recent years, there has been a growing interest in the impact of robots on the dynamics between humans (e.g., [1]–[10]). Robots were shown to shape and form human interactions in different contexts [3], [7], [11] and with different types of robots [3], [4], [6], [8], [9], [12]. These studies indicated that robots could impact conflict resolution [13], enhance humans' interpersonal evaluation [6], encourage balanced participation in group activities [9], and reduce awkwardness between people [7], [8]. An important aspect of human dynamics, that has been less studied in the context of Human–Robot Interactions (HRI), is emergent leadership in teams.

Teamwork is an important type of human–human interaction [14]–[16] that involves a group of interdependent individuals who act together to achieve a common goal [17], [18]. It is a dynamic process in which flexible cognitions, behaviors, and attitudes should be used to successfully perform collaborative tasks [14]. Teamwork is known to have various benefits, including efficient problem solving [18], skill development

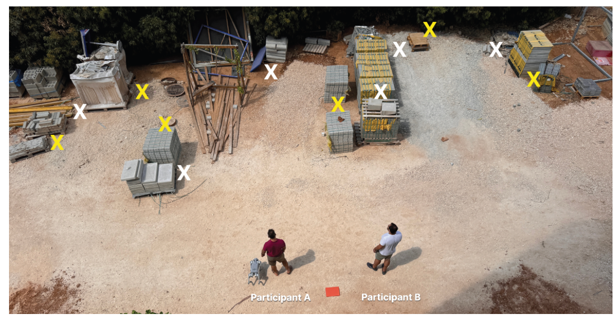

Fig. 1. The *Unequal Liking* condition. White 'X' indicates cubes with the relevant symbols; yellow 'X' indicates cubes without the relevant symbols. A task sheet is on the floor behind the participants

[19], [20], enhanced motivation [16], [20], and decreased burnout [16]. The quality of teamwork is known to heavily depend on the team's leadership [14], [21]–[23]. Prior work in psychology indicates that by taking responsibility and focusing on both the team's goal and needs, leaders can significantly facilitate teamwork [22], [24], enhance team cohesiveness [25], and motivate the positive behavior of team members toward each other [26]. The HRI literature has already indicated the advantages of integrating robots into teams [27], [28], and specifically their relation to leadership, ranging from the positive effects of robots acting as team leaders [29], [30] to the impact of integrating robots as leader assistants [31]–[36].

Traditionally, leadership studies from both the psychology and HRI domains have focused on formal leaders who have explicitly been given responsibility for the team (also known as vertical leadership [22], [37], [38]). These leaders typically prioritize power over enhancing inner-team processes and, as a result, miss out on some of the benefits associated with high-quality team leadership [39]. In recent years, there has been a growing interest in informal leadership, where no direct responsibility is formally assigned to any of the team members [22], [37]. This type of leadership, also known as emergent leadership, is based on social processes within the team, where

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team members informally accept one of the members (who does not have a formal status) as their leader [14], [40], [41]. Emergent leadership is known to have various unique benefits, including enhanced team cohesiveness, enhanced social support among team members [42], [43], enhanced sense of trust among team members [44], and increased commitment to team goals [45]. These benefits are believed to dramatically contribute to the team performance [45], [46]. It has also been suggested that robots can be programmed to identify emergent leadership processes and estimate the leader that would maximize team performance [47].

Several studies have explored the development of emergent leadership and identified the factors that facilitate it. These studies indicate that this type of informal leadership can be shaped only by social processes that emerge from within the team (for a recent review, see [21], [48]). One factor that has stood out as encouraging the emergence of leadership is peer liking [49]. Peer liking refers to the extent to which peers favor a specific team member in interpersonal interactions [50]. Being liked by others typically leads to social power and the development of various relationships [51]. This suggests that emergent leadership, with its unique benefits, will not necessarily emerge in any team as it depends on the team members' personalities and liking of each other. Moreover, it cannot be externally encouraged as it depends on the dynamics within the team. In this context, the integration of robots in teams presents an unexplored opportunity to facilitate emergent leadership. It is possible that integrating a robot that displays peer liking toward a specific team member could facilitate the informal leadership of that selected team member.

Peer liking in robots can be easily designed by applying simple robotic behaviors [9], [52], [53]. Among these behaviors, a robotic preference exhibited at the beginning of the interaction can have a powerful impact [54]. It is already well established that the opening encounter with a robot influences the valence and quality of the interaction that follows [2], [54]–[59]. A positive opening encounter with a robot typically leads to an overall positive experience and enhances the perception of warmth that lasts throughout the interaction [2], [54], [59]–[61]. This is attributed to a psychological mechanism that translates positive social cues in the opening encounter into a sense of belonging that sets the social foundations for subsequent interactions [62], [63]. Coupled with the understanding that emergent leadership is highly impacted by social cues [64], the social power of opening encounters suggests that a robot's peer liking displayed in the opening encounter can be leveraged to facilitate the emergence of informal leadership.

In this work, we evaluated the possibility of integrating a robot into a human–human team in a way that would encourage the emergence of leadership. We designed the robot to demonstrate peer liking in the opening encounter of a team interaction that involved a collaborative search task. The team consisted of two (stranger) participants and a robotic dog who were asked to decipher a code that consisted of unfamiliar symbols. The translation of the symbols could be found on cubes spread across an outdoor area (see Figure 1). We evaluated whether the robot's peer liking displayed at the opening encounter towards one (rather than both) of the participants would facilitate emergent leadership. We tested whether the explicit preference of one of the participants would facilitate that participant's tendency to lead the task and take over responsibility for task performance.

II. Related Work

Relevant prior research has evaluated how robots can shape human-human dynamics, the impact of a robot's preference for one participant in HHRI, and leadership in HRI.

A. Robots shaping human–human dynamics

Various studies have indicated that robots can easily impact and even shape interactions between humans (for a review, see [1]). Social robots have been shown to serve as facilitators, promoting collaboration between people [65]–[67], enhancing the inclusion of humans in an interaction [9], [12], [28], [68], [69], mediating conflicts between humans [13], [52], and influencing emotional aspects of the interactions between humans [7], [8], [11]. For example, Rifinski et al. [6] explored the impact of a non-humanoid robot on human–human interactions in conversational contexts. They found that minimal gaze and leaning gestures towards the speaker enhanced participants' interpersonal evaluation of each other. A similar robotic behavior was employed by Erel et al. [5], who demonstrated that when a person shares a challenge in a human–human interaction, a simple peripheral robot can enhance the emotional support provided by the other (human) participant in the interaction. The peripheral robotic modeling of the desired supportive and attentive behavior resulted in an interaction that involved a high sense of empathy and overall positive human–human interpersonal relationship. Likewise, Zhang et al. [70] found that a humanoid robot can facilitate meaningful connections between strangers. Participants were asked to stay in a waiting room while a conversation facilitator was introduced. The robotic facilitator was found to be effective in making participants converse on deep and intimate personal topics. Integrating a robot into human–human interactions has also been shown to lead to negative effects, impairing the interpersonal relationships between people [71]–[73]. For example, Sebo et al. [74] found that being the only team member who can communicate with a robot in a team collaborative task leads to feeling less included.

The above studies indicate the wide range of effects robots can have when integrated into human–human interactions. We extend this line of work by testing the possibility that a robot can shape emergent leadership in a team of two strangers when neither of them is formally assigned as the team's leader.

B. Impact of a robot's preference of one participant in human–human–robot interactions

A special case of robots shaping human–human dynamics concerns the impact of a robot preferring one participant over another. Previous studies have indicated both positive and negative effects from a robot's explicit preference of a specific human [9], [53], [73], [75]. A few studies have indicated that a robot can lead to more balanced human–human dynamics by preferring a specific participant [9], [52], [76]. For example, Tennet et al. [9] presented a robotic microphone designed to promote participants' engagement in decision-making discussions in three-person teams. By performing simple turn gestures towards a specific participant, the robot indicated its attentiveness toward that participant in an attempt to encourage the participant to take a more active part in the discussion. The simple gestures toward the more passive participant in the conversation led to increased engagement and more balanced human–human dynamics. Similarly, Neto et al. [68] demonstrated the potential of leveraging robots for enhancing inclusion in groups of children with mixed visual abilities. In the study, groups of three children (two sighted and one visually impaired) participated in decision-making activities. A robot that was integrated into the interaction expressed its preference for the least active speaker. The robot's direct preference balanced speaking time in groups in which one child spoke significantly more than others.

Robotic preference has also been shown to result in negative effects. Jung et al. [73] indicated that a robot's liking of one team member could impair the interpersonal relationships between the people in the team. In this study, participants performed a collaborative task of building the tallest tower possible from wooden blocks that they received from a robotic arm. Despite the collaborative nature of the task, when the robotic arm allocated the blocks unequally (i.e., gave one participant more blocks than the other), the two participants reported lower satisfaction with team relationships compared to teams in which the blocks were distributed equally. Expanding on this work, Claure et al. [75] developed an algorithm for a robot in human–robot teams that progressively favored "stronger" players (those who performed better). They showed that the robot's preference negatively impacted its perception.

These studies indicated that a robot's preference for one group member can impact group dynamics and the robot perception. We extend these studies by testing whether a robot's preference can also be leveraged to encourage a selected team member to become the informal leader of a team.

C. Leadership in HRI

Previous work has investigated different aspects of leadership in HRI, including contexts in which the robot is designed to lead humans and contexts where the robot follows a human leader [77]. These studies have focused on the acceptance and impact of robots as leaders [29], [30], [78]–[81] and the possibility of alternating leadership between human and robot team members to maximize team performance [82]–[85]. A few studies have also tested the impact of robots that follow human leadership [47], [79], [80], [86], [87]. These studies indicate that when robots follow human leadership, the leaders are perceived as more persuasive [80], the team performs better [79], [86], and team members report a greater sense of safety [88]. A slightly different perspective was taken by Kwon et al. [47], who introduced an algorithm that can identify leader–follower dynamics in human teams. They suggested that their algorithm can be leveraged by robots to signal that there is a need to switch leadership in order to reach better outcomes.

We extend these studies on leadership in HRI by testing whether a robot's peer liking, presented at the beginning of the interaction, can facilitate the emergence of human leadership.

III. Method

To test whether a robot can encourage emergent leadership by demonstrating peer liking towards one team member, we designed a search task where two participants (with no previous acquaintance) were asked to search for symbols on cubes with a robotic dog. To display peer liking, the robot performed a positive opening encounter by nodding repeatedly. We evaluated emergent leadership under two *Robotic Conditions*: 1) *Unequal Liking*: The robot's positive opening encounter indicated the robot's liking of one of the team members; 2) *Equal Liking*: The robot's positive opening encounter did not indicate a preference for any of the team members.

A. Search task and robot

1) Search task: In the search task participants were asked to look for cubes in an open area outside. On the cubes they could find the translation of unfamiliar symbols representing a code they had to decipher. They were given a task sheet that included a sentence coded with the symbols and were asked to translate the symbols into letters (see Figure 2, *Right*). Participants were informed that the translation of each symbol into a letter could be found on cubes spread across an open area outside. They were also informed that there were various symbols on each cube, and that some of them were relevant for the code while others were not. We intentionally chose an open area with many items to create a suitable environment for a search task (see Figure 1). Twelve cubes were spread across the open area. Each face of the cubes, except for the bottom, displayed an expression that indicated which English letter a symbol represented (for example, symbol "*=D" indicates that "*" represents the letter "D").

To increase the task difficulty, only six cubes had symbols relevant to the code (four cubes included one relevant symbol, and two cubes included two relevant symbols, resulting in eight different English letters). The four-word code "!#&% # $@@* *#;" translates into "Have a good day" when successfully deciphered. Several iterations were needed to create a task sufficiently complex to require mutual dependence and communication, supporting the emergence of leadership.

Fig. 2. *Left:* Robotic dog used in the experiment; *Right:* Task sheet used for managing the task, with the set of symbols.

Fig. 3. *Left - Equal Liking*: A - The robot performs an opening encounter in front of both participants; B - The robot standing between the participants; *Right - Unequal Liking*: C - The robot performs an opening encounter in front of a specific participant; D - The robot standing next to that participant.

2) Robot and gesture design: We used the Unitree Go1 robot, a small 15 kg quadruped with 12 degrees of freedom (see Figure 2, *Left*). We chose this robot since its behavior aligned with participants' pre-existing experiences with real dogs, minimizing the novelty associated with the HRI context. The robotic dog also allowed us to avoid social complexities related to language and speech tone [54], [89], [90]. The robot was operated remotely using the Wizard-of-Oz method, where the researcher controlling the robot was out of sight [91], [92].

To design the robot's demonstration of peer liking in the opening encounter, we used a robotic behavior that was designed and validated to indicate a positive greeting in previous studies using robotic dogs [54], [90]. The robot approached the participants and upon reaching a distance of approximately 65 cm from them, it positioned itself in front of the participants: either directly in front of one of the participants (*Unequal Liking* condition; see Figure 3 C) or in front of both participants (*Equal Liking* condition; see Figure 3 A). It then turned its front part up twice (simulating nodding) in the direction of one or both participants.

To further enhance the robot's demonstration of peer liking, we also manipulated its interpersonal distance from the participants. Prior work from psychology indicates that physical distance is a robust social cue representing closeness and social distance [93]–[95]. Smaller physical distances are associated with greater emotional closeness, greater empathy, and greater willingness to take part in an interaction [96]–[101]. Similar effects have also been indicated in the context of HRI, where the physical distance between a human and a robot was interpreted as representing the relationship between them [102]. We therefore manipulated the robot's interpersonal distance from the participants under both conditions. In the *Unequal Liking* condition, the robot finished the opening encounter by moving closer to the "Liked" participant and standing next to him\her, on the far side with respect to the other participant (see Figure 3 D). In the *Equal Liking* condition, the robot finished the opening encounter by moving closer to the area between the participants and standing between them at an equal distance from each participant (see Figure 3 B).

We additionally designed three gestures for the search task: *Understanding*, to indicate that the robot understood the task given to it by the participants; *Scanning*, to indicate that the robot was scanning the symbols on the cube; and *Finding*, to indicate that the robot has found a symbol. They were performed as follows: (1) *Understanding*: When the participants addressed the robot, it entered a position simulating a dog sitting and moved its head gently right and left as if mapping the information presented. It then turned its front part up towards the participant twice (nodding); (2) *Scanning*: To scan, the robot leaned towards the cube (lowering its front part towards the cube) and performed right–left rotations of its head (indicating its focus and scanning of the cube); (3) *Finding*: To indicate finding a relevant symbol, the robot performed a scanning gesture followed by a ($\pm 360°$) turn next to the cube.

The gestures were designed via several iterations with an animator and an HRI expert, 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 28 participants who were asked to explain the meaning of the gestures (presented in counterbalanced order). All participants easily understood the gestures.

B. Participants

Forty pairs of participants (with no previous acquaintance) participated in the study (80 participants, 44 women and 36 men; mean age = 24.78, SD = 4.25). All participants signed a consent form and received extra course credits or a 25 USD gift card. To control for possible gender influences (see [103], [104]), we tested single-gender pairs.

C. Experimental setting

The experiment was conducted in an open area outside one of the university buildings. The open area was in a quiet environment with bushes and building materials, which made it possible to hide the 12 cubes. The participants began the experiment in a location that was marked as the beginning point. The task sheet with the code was placed on the ground behind the participants at an equal distance from both (see Figure 1). The robotic dog was positioned out of sight and noticed by the participants only when it moved towards them.

D. Experimental design

This experiment used a 2×2 between-participant experimental design that included the following two factors: 1) *Robotic Condition* and 2) *Within Pair Labeling*. The *Robotic Condition* factor was designed to compare two robotic behaviors: 1) *Unequal Liking*: The robot preferred one of the participants. The robot began its movement from one side of the field. It then proceeded toward one specific participant. The robot faced that participant and performed the opening encounter gesture (see Figure 3 C). The robot ended the opening encounter by positioning itself next to that participant (see Figure 3 D). 2) *Equal Liking*: The robot began its movement from one side of the field. It arrived at a location in front of and between the two participants and turned to face them. The robot then performed the opening encounter gesture towards both participants (see Figure 3 A). The robot ended the opening encounter by positioning itself between the two participants (see Figure 3 B). The *Within Pair Labeling* factor was designed to evaluate the different experiences of the participants within each pair. We were interested in mapping whether the two participants had different experiences (e.g., one participant reported a higher sense of leadership in comparison to the other participant in that pair). We randomly labeled each participant in a pair as Participant A or Participant B. In the *Unequal Liking* condition, we consistently designed the robot to display liking only toward Participant A. In the *Equal Liking* condition, both Participants A and B were "Liked" by the robot. The participant pairs were randomly assigned to the different conditions. We verified that groups were balanced using two relevant pre-tests: Motivation to Lead (MTL, trait; [105]) and General Attitudes Toward Robots (GAToRS; [106]).

E. Dependent variables

We assessed the impact of peer liking on emergent leadership using self-report and behavioral measurements.

1) Self-perceived leadership rating: We measured self-perceived leadership using a 6-point Likert scale, where team members evaluated their leadership in the task. The questionnaire items were adapted from Lanaj and Hollenbeck [107].

2) Responsibility perception: Participants were asked to report to what extent they felt responsible for the team's performance on 10-point Likert scale [108], [109].

3) Behavioral measures: To measure participants' leadership, we also used behavioral measures: 1) which participant picked up the task sheet to manage the task 2) the amount of time each participant managed the task by holding and filling in the task sheet. Two independent coders reviewed the videos and verified that their coding was consistent.

4) Robot perception: We also evaluated the robot's perception using the Robotic Social Attributes Scale (RoSAS), which is a 9-point Likert scale (1: "low" and 9: "high") constructed of three sub-scales: warmth, competence, and discomfort [110].

5) Qualitative measure - Semi-structured interview: A semi-structured interview was conducted to better understand the participants' thoughts and attitudes [111]. The interview was designed to understand participants' thoughts about the experience, the task, the other participant, and the robot (e.g., "Describe your experience" and "What did you think of the other person who performed the task with you?"). Participants were interviewed separately in different rooms.

F. Procedure

A few days before the experiment, participants received an email with pre-test questionnaires including the MTL [105], GAToRS [106], and demographics. Upon arriving at the lab, participants were led to the open area outside the building. The researcher asked the two participants to stand in front of the open area in two marked spots and told them that they were about to perform a task as a team and that a robotic dog would join their team shortly. The researcher then instructed them to wait a few seconds until the experiment began and moved out of sight to allow them to pay full attention to the approaching robotic dog. The robotic dog then joined the participants and performed the opening encounter behavior, demonstrating peer liking according to the relevant condition. In particular, this was the only time the robot demonstrated peer–liking behavior during the task. The researcher then returned and explained the task, asked participants to pick up the task sheet placed behind them, and emphasized that the team's task was to decipher the code together in the most efficient way. Next, the researcher set the participants' expectations of the robotic dog's capabilities, explaining that it could search for symbols and signal with a gesture when it found a relevant symbol. The researcher asked the participants to plan a strategy for the search task and explain it to the robotic dog (this procedure determined the robot's behavior during the task). While search strategy varied across participants, the robot performed accurately in all cases. After the participants explained to the robot what it should do, the robot performed the understanding gesture and turned toward the open space, signaling that it was ready to begin. The participants then performed the search task, which ended after they had deciphered the code. Immediately after the participants finished the task, they filled out the questionnaires and participated in a short interview (separately and in different locations). The researcher debriefed the participants and verified that they left with a positive experience.

IV. Analysis

To verify the lack of early differences between groups, we conducted Bayesian analyses (simple Cauchy prior) on all pre-tests. The robot's impact on emergent leadership was analyzed using a two-way ANOVA for sense of leadership, sense of responsibility, and time managing the task by filling in the task sheet. The impacts of two independent factors were evaluated: 1) *Robotic Condition – Equal Liking* vs. *Unequal Liking* (peer liking) and 2) *Within Pair Labeling* – Participant A or Participant B, representing the different experience within each pair (see Section III-D). We also conducted a chi-square analysis to test the dependency between the *Robotic Condition* and the participant who initially picked up the task sheet to manage the task. The interviews were analyzed using thematic coding [111], which included transcriptions and review of all interviews, identifying initial themes in a process that involved three researchers who independently identified repeating patterns, discussed inconsistencies, and reached mutually agreed themes. The researchers independently analyzed a subset of the interviews to verify inter-rater reliability (Kappa = 88%) and analyzed the remaining data.

V. Results

The Bayesian analysis indicated no early differences (GAToRS: $BF_{10} = 0.29$; MTL: $BF_{10} = 0.22$). The main

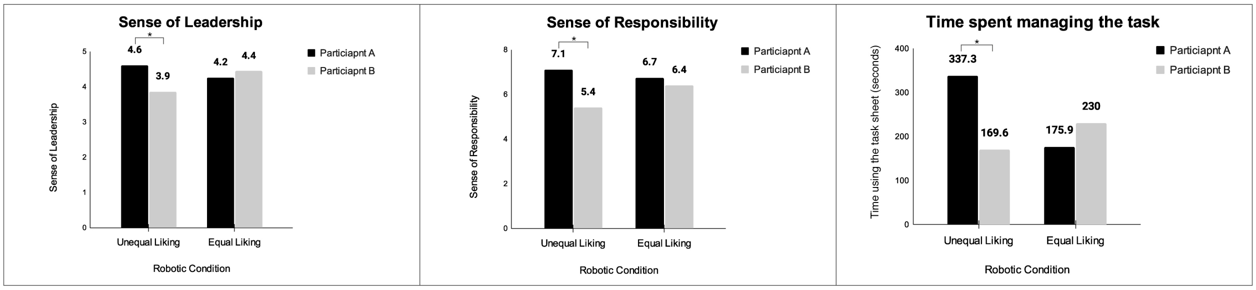

Fig. 4. Impact of *Robotic Condition* and *Within Pair Labeling* (see III-D), on leadership (*Left*); responsibility (*Center*); and time managing the task (*Right*).

analyses indicated the robot's impact on emergent leadership.

A. Self-perception leadership

The two-way ANOVA revealed a significant interaction between the *Robotic Condition* and the *Within Pair Labeling*, $F_{(1,76)} = 4.76$, $p = 0.032$, $\eta_p^2 = 0.06$. Post-hoc analyses using planned contrast indicated that under the *Equal Liking* condition, Participant A ($M = 4.2, SD = 1.1$) and Participant B ($M = 4.4, SD = 1$) reported similar perceived leadership ($p_{contrast} = 0.6$). Conversely, under the *Unequal Liking* condition, Participant A (who was "Liked" by the robot; $M = 4.6, SD = 0.89$) reported higher leadership than Particiapnt B ($M = 3.9, SD = 0.91$; $p_{contrast} = 0.018$; Figure 4, Left). Hence, as a result of the robot's liking for one participant, that participant experienced a stronger sense of leadership than the "Non-Liked" participant. No main effects were observed.

B. Responsibility during the search task

The two-way ANOVA analysis revealed a significant interaction between the *Robotic Condition* and the *Within Pair Labeling*, $F_{(1,76)} = 4.04$, $p = 0.048$, $\eta_p^2 = 0.09$. Post-hoc analyses using planned contrast indicated that under the *Equal Liking* condition, Participant A ($M = 6.7, SD = 1.3$) and Participant B ($M = 6.4, SD = 1.1$) reported similar responsibility ratings ($p_{contrast} = 0.76$), while under the *Unequal Liking* condition, Participant A (the one "Liked" by the robot; $M = 7.1, SD = 1.4$) reported taking more responsibility than Participant B ($M = 5.4, SD = 1.8$; $p_{contrast} = 0.002$; see Figure 4, Center). Hence, when the robot preferred one of the participants, that participant reported taking more responsibility for the task. The *Within Pair Labeling* main effect was significant, $F_{(1,76)} = 6.1$, $p = 0.015$, $\eta_p^2 = 0.12$. The *Robotic Condition* main effect was not significant.

C. Picking up the task sheet

The chi-square analysis revealed a significant dependency between the *Robotic Condition* and *Within Pair Labeling*, $\chi^2_{(1)} = 3.75, p = 0.05$. Under the *Equal Liking* condition, there were hardly any differences, and either Participant A or B would pick up the task sheet. Under the *Unequal Liking* condition, Participant A ("Liked" by the robot) was the one who picked up the task sheet (see Table I).

D. Time spent managing the task

The two-way ANOVA analysis revealed a significant interaction between the *Robotic Condition* and *Within Pair Labeling*, $F_{(1,76)} = 5.76$, $p = 0.019$. Post-hoc analyses using planned contrast revealed that under the *Equal Liking* condition, there was no significant difference between the time each participant managed the task (Participant A, $M = 175.9, SD = 44.77$; Participant B, $M = 230, SD = 38.16$; $p_{contrast} = 0.4$), whereas under the *Unequal Liking* condition, Participant A managed the task longer ($M = 337.3, SD = 53.70$) than Participant B ($M = 169.6, SD = 48.32$; $p_{contrast} = 0.015$; see Figure 4, Right). Hence, when the robot liked one of the participants, that participant was more dominant in managing the task[1].

E. Robot perception

The two-way ANOVA analysis of the RoSAS did not reveal any significant effects in the sub-scales.

F. Qualitative: Semi-structured interviews

In total, 593 quotes were coded into three main themes: leadership and responsibility, dynamics with other team members, and the influence of the robot on team members.

1) Theme 1 - Leadership and Responsibility: Leadership was discussed by 74/80 participants. Some participants perceived themselves as leaders, others perceived the other participant as the leader, and some described how leadership was shared. Under the *Unequal Liking* condition, 39/40 participants discussed leadership. However, the participants within each pair demonstrated different attitudes. Among those who were "Liked" by the robot, 12/20 participants perceived themselves

[1] Appendix A

TABLE I
DISTRIBUTION OF WHICH PARTICIPANT PICKED UP THE TASK SHEET.

Robotic condition	Participant picking up the task sheet		Total
	Participant A	Participant B	
Unequal Liking	15	5	20
Equal Liking	9	11	20
Total	24	16	40

as the team's leader: *"I led. I said what we should do and we did it. She didn't offer anything else."* (P.48, F). A few participants also reported that they shared leadership with the other participant (7/20): *"We shared the responsibility, communicated equally with the robot, and found symbols."* (P.22, M). Only one participant who was "Liked" by the robot described the other participant as the leader (1/20): *"I was the one who started the task but at some point he took over."* (P.1, M). The participants who were "Not-Liked" by the robot, demonstrated an opposite pattern. Only one participant reported leading the team (1/20): *"I felt that I managed the task."* (P.78, M). A few participants reported sharing leadership with the other participant (7/20): *"I threw out an idea, and he threw out an idea. So no one was the clear leader."* (P.21, M). The other participants who were "Not-Liked" by the robot reported that the other participant led the team (11/20): *"She really stepped into a leadership role. She did it nicely, not giving me direct instructions."* (P.33, F).

Under the *Equal Liking* condition (no difference in the robot's liking), 35/40 participants discussed leadership. More than half (22/40) mentioned that they shared leadership with the other participant: *"I felt that we were together in it, that we are on the same page, synchronized."* (P.11, F). In addition, 11/40 participants reported that they were the team leaders: *"I was the leader. I explained the strategy, I took control, and I wrote down the code."* (P.64, F). Only 2/40 participants perceived the other as the team's leader: *"She was like the leader. She wrote the code in the sheet."* (P.16, F).

2) Theme 2 - Dynamics with other team members: Team dynamics were discussed by 78/80 participants. Under the *Unequal Liking* condition, 40/40 participants discussed team dynamics. However, participants within the pairs demonstrated different attitudes. Most participants who were "Liked" by the robot reported positive dynamics (16/20). They described teamwork and consideration of the other participant: *"I planned a strategy and asked if she was okay with it. We worked well together"* (P.7, F). Only 4/20 reported negative dynamics: *"She didn't understand; it was a mess."* (P.19, F). Amongst the participants who were "Not-Liked" by the robot, half (10/20) reported positive dynamics, stating that they contributed to the team effort: *"We worked in collaboration and searched for the symbols together."* (P.14, F). The other half of the participants who were "Not-Liked" by the robot reported negative team dynamics (10/20), explaining that the interaction was not balanced: *"I felt she was more connected to the robot and wanted to start right away."* (P.20, F).

Under the *Equal Liking* condition (no difference in the robot's liking), 38/40 discussed team dynamics. Almost all participants reported positive dynamics (37/40): *"I had fun with her, we were in a flow; great teamwork."* (P.43, F). Only one participant in this condition described negative team dynamics (1/40): *"In the end, we needed to divide resources. So he went with the robot, and I went by myself."* (P.6, M).

3) Theme 3 - The influence of the robot on team members: The robot's influence was discussed by 27/80 participants. Under the *Unequal Liking* condition, 14/40 participants discussed the robot's influence. However, the participants within the pairs shared different perception of the robot's impact. Participants who were "Liked" by the robot described only positive influences (10/20): *"He sat next to me, like a wingman. It's like in the* Borat *movie, as if he says, 'You are the King of the Castle.'"* (P.51, M). In contrast, participants who were "Not-Liked" by the robot either did not mention any robotic influence or described a negative impact (4/20): *"He looked at us and stood beside the other person. Honestly, it pissed me off. I wanted him to stand between us."* (P.10, M).

Under the *Equal Liking* condition (no difference in the robot's liking), 12/40 participants described positive influences. They explained that the robot enhanced the team's ability to perform the task: *"He stood between us, and it made me feel that he was committed to us... another great team member that would help us perform the task."* (P.36, F). Only one participant from this condition described a negative influence (1/40): *"I felt weird, uncomfortable."* (P.54, F).

VI. Discussion

In this work, we demonstrated the potential of leveraging robots to encourage emergent leadership. By integrating a peer robot designed to "Like" a specific team member, we showed how the dynamics between people in a team can be shaped and how informal leadership can develop. Our findings further indicate that peer liking displayed at the beginning of the interaction is sufficient for setting the leadership dynamics in the rest of the interaction. A positive encounter directed by the robot towards a specific participant encouraged responsibility taking and leadership of the team. These effects were observed even though participants were not asked to choose a leader and leadership was not required to perform the task. Being "Liked" by the robot led to higher ratings of self-perception of leadership and responsibility. Furthermore, the "Liked" team member showed greater tendencies to pick up the task sheet and spent more time using it to manage the task.

Interestingly, when the robot did not show a preference toward a specific participant (*Equal Liking*), frequently non of the participants develop a tendency to lead. This suggests that an informal leader may not emerge without an external intervention designed according to the relevant social requirements, and the advantages of emergent leadership would be missed. Simply adding a robot to a team is not likely to facilitate leadership unless the robot is designed according to the social requirements that support emergent leadership (i.e., peer liking). By contrast, if a more balanced team work is desired, our findings imply that it can be facilitated by introducing to the team a robot that displays mutual liking. While not directly tested in this study, our qualitative findings strongly suggest that under the *Equal Liking* condition, participants perceived the interaction as high-quality collaborative teamwork. We therefore suggest that integrating unequal liking robotic behaviors is appropriate when leadership is a priority and equal liking is appropriate when team balance is a priority.

Our findings extend the scope of human social dynamics that can be shaped by robots [1], [112]. Specifically in the context of leadership, previous studies indicated robots' ability to lead human teams and the possibility of alternating between human and robotic leadership [29], [78]–[80], [83]–[85]. We extend this literature by demonstrating that robots can shape and facilitate human leadership in teams that do not have a formal leader. Most participants under the *Unequal Liking* condition, both those who were and were not "Liked" by the robot, exhibited advantages of emergent leadership and a positive impact on team dynamics (*"She really cared about my opinion. We had great teamwork."*). At the same time, our findings also indicated that the robot's peer liking could lead to some negative effects. The clear preference of one team member led in some cases to a sense of social imbalance. A few of the participants who were not "Liked" by the robot were not satisfied by the team dynamics (*"It was kind of divide and conquer instead of working together."*). This effect should be further studied to minimize any negative effects related to the robot's preference of one team member over the other.

Another implication of our results concerns the importance of opening encounters with robots. While psychology studies indicated the long-term impact of opening encounters on subsequent interactions [63], in HRI, the impact of opening encounters was tested by evaluating participants' tendencies to help the robot shortly after the opening encounter [54], [55], [59]. Our findings indicated that similarly to human interactions, opening encounters with robots can have a long-term effect that influences the entire interaction. The "Liked" participant in the *Unequal Liking* condition led the interaction throughout the experiment and managed it using the task sheet. The leadership of the task was not often alternated between the participants, and the impact of the robot's behavior in the opening encounter lasted until the task was completed. We therefore further demonstrated the importance of carefully designing opening encounters with robots due to their powerful, long-lasting impact on the interaction that follows.

Taking a broader perspective, we suggest that people's tendency to interpret interactions with robots as social experiences (see [113]) extends to the phenomenon of peer liking and its implications on emergent leadership. Similar to the impact of being liked by human team members, a robot's liking displayed by simple robotic non-verbal behavior was sufficient for facilitating the emergence of informal leadership. Despite the robot's mechanical nature and its inability to engage in a verbal interaction, its simple social cues led participants to experience a clear sense of peer liking *(e.g., "He was committed to me" or "It chose me.")*. The robot's peer liking toward one team member resulted in an effect on leadership that is typically observed in the presence of human peer liking. This implies that similar to interactions with humans [49], interactions with a robotic team member can grant the social power required to empower a specific team member and encourage the development of leadership. This suggests that robots present a strong opportunity for facilitating emergent leadership (which is known to have special advantages).

Taken together, our findings suggest that integrating a robot into a human team can be leveraged to shape team dynamics that might otherwise be difficult to control or manage. Such robotic behavior can facilitate the quick formation of teams where it is important that all team members quickly accept a leader while maintaining meaningful contributions. For example, experts with different skills gathered for brainstorming sessions to solve urgent problems. The team members' different skills should be integrated into collaborative teamwork [114] so that every member's input is valued. Such teams can benefit from leadership that would maximize performance by organizing teamwork while respecting and empowering all team members. This requires leadership that emerges from within the team [115], [116]. Similarly, in emergencies, teams of rescue forces who may not know each other should work together. Under such circumstances, emergent leadership may have great advantages over a formal one since accepting an external leader may take time and lead to frustration. The robot's impact at the opening encounter can be a good fit for such high pace events. Leveraging a robot to support emergent leadership can also facilitate the acceptance of formal leadership. Adding a preliminary team activity with a robot when constructing new teams (e.g., in sports) can prime the leadership of a team member that would later be introduced as a formal leader (e.g., captain). In all of these cases, the robot can encourage social processes that are not commonly influenced by individuals who are not part of the team.

VII. Limitations

The robot used in the study was perceived as highly competent. It is possible that peer liking demonstrated by simpler robots would not have a similar impact. Another limitation concerns the robot's position in the *Unequal Liking* condition, which placed the chosen participant at the team's center. However, if the central position impacts leadership, we would expect the robot to be perceived as a leader in the *Equal Liking* condition (which did not happen). Additionally, we used a simple search task since our focus was on evaluating emergent leadership. Future studies should use a more complex task and evaluate the impact of emergent leadership on performance. Future work can also provide deeper understanding of the robot's effect by observing fluency matrices (distance from the robot, responsibility of the robot, verbal interactions, different performance of team members). Such behaviors can be analyzed based on Heider's balance theory (see [117]).

VIII. Conclusion

We highlight the potential of leveraging robots to encourage emergent leadership in teams. We demonstrated how robotic peer liking toward a specific team member during an opening encounter can shape informal leadership. Robots, therefore, present an opportunity to assist and intervene organically in the social dynamics within a team while preserving the benefits commonly lost when presenting external interventions.

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