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SHORT-PAPER

Human Perceptions of Warmth and Competence in Swarm Robot Behavior

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Human Perceptions of Warmth and Competence in Swarm Robot Behavior

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Abstract

As robots become increasingly embedded in human–robot teamwork, understanding how humans perceive robot behavior is critical. This is especially relevant for swarm robots that rely on collective behavior to accomplish tasks. While prior research has explored how humans evaluate the abilities and behaviors of single robots, the perception of swarm robots remains relatively underexplored. Guided by the competence–warmth framework, we conducted a perception-based experiment in a collective search task, generating 125 robot teams by systematically manipulating three parameters: speed, separation distance, and local broadcast duration. Ninety participants observed the swarms, rated perceived warmth and competence, and reported team preferences. Results show that broadcast duration increased perceived warmth, separation distance enhanced perceived competence, and individual robot speed had no significant effect. Critically, social perceptions of warmth and competence were stronger predictors of team preference than task performance, with participants favoring swarms that appeared warm and competent over those that completed tasks fastest. These results underscore the importance of considering both technical performance and social attributes when designing robot swarms for effective collaboration with humans.

CCS Concepts

• **Human-centered computing** → **Human computer interaction (HCI)**.

Keywords

Social Perception, Swarm Robotics, Multi-Robot Systems, Collective Behavior, Warmth, Competence

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1 Introduction

Swarm robotics investigates systems in which multiple robots coordinate their behavior to achieve shared objectives [9]. Unlike individual agents that prioritize their own goals, robots in swarms seek to achieve collective goals, and thereby may demonstrate capabilities that exceed the capabilities of individual robots [3, 13]. As robots increasingly operate in human environments, recent work has explored human–swarm teaming, primarily focusing on improving objective task performance [16, 21, 34]. However, relatively little work has examined how humans perceive these swarm behaviors, despite evidence that such perceptions play a critical role in shaping trust [31, 34] and preferences for specific agents [7, 14, 26].

Humans commonly evaluate both individuals and groups along two core social dimensions, warmth and competence [11]. Competence captures perceived capability, such as intelligence or skill, while warmth relates to perceived intent, including friendliness and helpfulness. Research in human–robot interaction (HRI) has shown that these dimensions similarly influence how people respond to robotic agents. Robots perceived as high in both competence and warmth are generally associated with greater trust, whereas robots seen as competent but lacking warmth often elicit more cautious or reduced trust responses [14, 25]. Existing studies have primarily examined single-robot settings [26, 38], yet interactions involving multiple robots or swarms may introduce qualitatively different dynamics [7, 18]. Investigating how warmth and competence operate in human–swarm contexts is therefore essential for informing the design of socially effective swarm systems.

In this paper, we make the following contributions:

Establishing a social perception framework for robot swarm behaviors. We present, to our knowledge, the first empirical study to systematically examine how the social perception dimensions of warmth and competence shape human perceptions of robot swarms.

Identifying design principles for socially preferred swarm behaviors. By manipulating robot parameters including speed, separation, and broadcast duration, we generated distinct swarm behaviors that were consistently perceived as highly warm and competent. These findings provide an empirical foundation and offer concrete guidance for the future design of socially preferred robot swarms.

Demonstrating the role of social perceptions in team preference. Our results indicate that human team preferences are driven more by perceived warmth and competence than by task performance alone. This suggests that social perception should be treated as a primary factor in the design of robot swarms alongside the objective task performance.

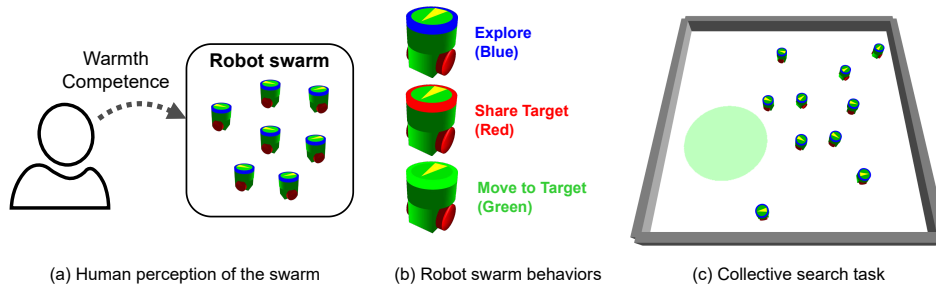


Figure 1: Experimental setup for assessing human perception of robot swarm behaviors.

The rest of the paper is organized as follows. Section 2 reviews related work on human social perception of single and swarm robots. Sections 3 and 4 presents our methods and results. Finally, Section 5 conclude with discussion and implications.

2 Related Work

Warmth and competence are well-established core dimensions of social perception that shape human social interactions [5, 6, 11], even results in strong stereotypes or biases towards individuals or groups [4, 12, 15]. Prior studies in HRI have examined social perception primarily in the context of single agents or individual robots, showing that specific robot behaviors and design features can systematically shape these perceptions [22, 33, 38]. In addition, prior research indicates that agents or robots perceived as both warm and competent are generally preferred as team members in human-agent collaboration tasks [14, 26].

Swarm robots, however, exhibit fundamentally different behavioral characteristics than individual robots. They operate as multiple, often homogeneous agents, are typically controlled in a decentralized manner, and are capable of self-organization, allowing them to dynamically adapt to changing situations through emergent collective behaviors [43]. Research comparing human interaction with single versus multiple robots further suggests that humans experience different emotional and cognitive demands when interacting with one robot versus several robots simultaneously [18], indicating that people may form different perceptions of the behavior of individual robots compared to robot collectives. Together, these differences suggest that findings from single-robot HRI may not directly generalize to human-swarm interaction.

With the rapid advancement of swarm robotics, particularly in autonomous execution of complex tasks, new challenges have emerged in designing swarm behaviors that are preferred by human users as team members and that can effectively interact with humans in human-robot teams. Prior work in human-swarm interaction has largely focused on enhancing technical capabilities for collaborative tasks with one or more human partners [17, 29]. Some studies have also explored social perception through trust, examining how users calibrate reliance on swarm performance and how trust influences task outcomes [24, 42]. Other work has investigated the expressivity of swarm movements, showing that coordinated patterns can convey affective states such as happiness or sadness [8, 19, 37, 41]. Despite these efforts, it remains unclear how humans perceive the broader social characteristics of robot

swarms and how specific swarm parameters (e.g., speed, separation, broadcasting) influence these social perceptions.

To address these questions, we developed physics-based simulations in which a robot swarm collaboratively searched for and approached target locations. Building on prior work in swarm behavior design [20, 29], we designed distinct swarm behavior patterns and systematically examined how humans form social perceptions of warmth and competence across different swarm behaviors (see illustrations in Figure 1 and Supplementary Video).

3 Methods

3.1 Swarm Behavior Design

We modeled a homogeneous swarm of 10 e-pucks [30], a widely used mobile robot in swarm robotics, using the ARGoS simulator [35]. The robot measures 7 cm in diameter and uses a differential-wheel drive. In our setup, robots are assumed to know their global position but lack global communication capabilities. Instead, they rely on a range-and-bearing module that supports local communication with nearby robots within 36 cm (center-to-center).

Figure 1 illustrates the experimental setup. The robots operate in a 150 cm × 150 cm arena and begin each trial at uniformly random positions and orientations. After three seconds, a circular target region with a 25 cm radius appears at a random location. Robots can detect whether their center is inside this region, but cannot sense the position of other robots. The swarm’s goal is for all robots to reach the target region as quickly as possible. This requires each robot to explore the area, locate the target individually or with the help from others, and move towards it.

3.1.1 Robot swarm behaviors. To enable all robots to efficiently arrive at the target location, we instructed the robots to perform the following three behaviors, with each behavior signaled to participants using distinct LED lights, as illustrated in Figure 1.

- (1) **Explore.** Each robot explores the arena using ballistic motion [20], moving straight at a constant speed v and performing an in-place turn of random duration whenever it encounters a wall or another robot. The turning direction depends on which side the obstacle is sensed—left if detected on the right, and vice versa. Walls are detected with 10 cm-range proximity sensors, and robots use their range-and-bearing sensors to maintain a desired distance d from one another.
- (2) **Share target.** When a robot discovers the target region, it broadcasts the target’s location to nearby robots for a

fixed duration T , while continuing to move exactly as it does during exploration. Any robot that receives this information for the first time also rebroadcasts it for T seconds, allowing the target location to spread through the swarm.

- (3) **Move to target.** After broadcasting the target’s position for T seconds, the robot navigates toward the target using a flocking behavior based on virtual potential forces [28], combining attraction to the target center with mutual repulsion. This enables the swarm to converge inside the target region while avoiding collisions.

3.1.2 Behavioral parameters. To produce different swarm behaviors, we systematically adjusted three parameters of the strategy:

- **Speed:** $v = 5.0, 7.5, 10.0, 12.5, 15.0$ cm/s.
- **Separation distance:** $d = 4, 12, 20, 28, 36$ cm.
- **Local broadcast duration:** $T = 0, 4, 8, 12, 16$ s.

These parameters and their ranges were selected based on the physical capabilities of the e-puck robots. Speed captured feasible locomotion, separation distance controlled inter-robot spacing, and local broadcast duration determined how long a robot shared target information with its neighbors. Combining five levels of each parameter yielded 125 swarm configurations (5 speed levels \times 5 separation distances \times 5 broadcast durations). Task performance was measured as the time required for all robots to reach the target region, with shorter times indicating better performance. Parameter checks confirmed that the selected ranges produced a wide distribution of completion times (13 s to 103 s) and that each parameter significantly affected task performance ($p < 0.001$).

4 Experiment

4.1 Participants

We recruited 90 participants through Prolific (45 female, 45 male; $M_{\text{age}} = 29.6$ years, $SD_{\text{age}} = 4.5$). The sample size was determined to ensure that each robot team was evaluated by at least 10 participants, supporting stable estimation of stimulus-level effects in later analyses. All participants reported normal or corrected-to-normal vision. Informed consent was obtained prior to participation, and participants were compensated at £12/hour. The study protocol was approved by the Faculty of Engineering Research Ethics Committee, University of Sheffield (Reference ID: 068772).

4.2 Procedure

Participants first viewed a short demonstration to familiarize themselves with the experimental setting and the robot behaviors described in Section 3.1 (see Figure 1 and the Supplementary Video). They were informed that the goal was for all robots to reach the target region as quickly as possible. Participants then observed multiple robot teams performing the task and rated each team on perceived warmth, competence, and team preference. Perceived warmth (“How friendly, approachable, or cooperative is the group of robots?”) and competence (“How capable, effective, and intelligent is the group of robots?”) were assessed using 7-point Likert scales adapted from [26], consistent with the standard operationalization of the warmth–competence framework in prior human–human [5, 10] and human–agent social perception studies [25]. Each participant evaluated 15 randomly selected robot teams in random

Table 1: LME models examining the influence of robot swarm parameters on warmth & competence.

Predictor	Estimate	SE	t	p-value
<i>Model for Warmth Ratings</i>				
Speed	-0.002	0.020	-0.111	0.912
Separation	0.011	0.006	1.814	0.070
Broadcast	0.043	0.012	3.565	0.0004
<i>Model for Competence Ratings</i>				
Speed	0.014	0.022	0.619	0.536
Separation	0.018	0.007	2.564	0.010
Broadcast	-0.013	0.014	-0.903	0.367

Note. Significant predictors ($p < .05$) are highlighted in bold.

order, with the rating sequence counterbalanced to mitigate order effects. Afterward, participants completed a brief post-task questionnaire and provided free-text descriptions of robot behaviors they perceived as warm or competent.

4.3 Results

4.3.1 Robot Swarm Behaviors Elicited Diverse Social Perceptions.

We first examined the overall distribution of ratings across all participants and robot teams. Results showed that the robot swarm behaviors elicited a broad range of social perceptions, spanning low to high values for each dimension. Ratings were slightly skewed toward higher values for warmth ($Min = 1.00, Max = 7.00; M = 4.73, SD = 1.62$) and competence ($Min = 1.00, Max = 7.00; M = 5.08, SD = 1.52$). We further examined how specific robot swarm parameters (i.e., speed, separation distance, and local broadcast duration) influenced participants’ perceptions of warmth or competence using a linear mixed-effects (LME) model:

$$\text{Warmth (or Competence)}_{ij} = \beta_0 + \beta_1 \text{Speed}_{ij} + \beta_2 \text{Separation}_{ij} + \beta_3 \text{Broadcast}_{ij} + u_j + \epsilon_{ij}. \quad (1)$$

where i indexes the robot team in each trial, j indexes the participant, $u_j \sim \mathcal{N}(0, \sigma_u^2)$ is the participant-specific random intercept, and $\epsilon_{ij} \sim \mathcal{N}(0, \sigma^2)$ is the residual error. This model enables us to assess how each swarm parameter influenced social perceptions.

Table 1 summarizes the results. Warmth ratings were significantly predicted by broadcast duration ($p < 0.001$), with longer information-sharing durations associated with higher perceived warmth. Competence ratings were significantly affected by separation distance ($p = 0.01$), such that more widely spaced robots—which were associated with improved task performance—were perceived as more competent. Individual robot speed did not significantly influence either warmth or competence. Mixed-effects models including all two- and three-way interactions replicated our main findings. No interactions were significant for warmth (speed \times separation $p = 0.14$, speed \times broadcast $p = 0.26$, separation \times broadcast $p = 0.26$; three-way $p = 0.35$) or competence ($p = 0.21, 0.47, 0.29$ respectively; three-way $p = 0.56$).

4.3.2 Social Perception Predicts Team Preference beyond Task Performance.

Prior work suggests that social perceptions of warmth and competence are stronger predictors of team preference than

Table 2: LME model predicting team preference from social perceptions and task performance (standardized).

Predictor	Estimate	SE	t	p-value
Warmth	0.739	0.030	24.73	< 0.001
Competence	0.924	0.031	29.70	< 0.001
Task Performance	0.121	0.024	5.02	< 0.001

Note. Significant predictors ($p < .05$) are highlighted in bold.

objective performance in human–agent collaboration [14, 26]. We tested this by modeling how warmth, competence, and task performance predict team preference using a linear mixed-effects model. Task performance was measured as the time to complete the task and thus reversed for interpretability (higher values = better performance), and all predictors were z-scored to enable comparison of effect sizes.

Table 2 summarizes the results. Warmth ($\beta = 0.74$) and competence ($\beta = 0.92$) strongly predicted team preference, while task performance had a smaller but significant effect ($\beta = 0.12$) (all $p < 0.001$). These findings indicate that participants’ preferences were driven more by social perceptions than by objective task performance.

To visually illustrate these effects, Figure 2 shows the relative contributions of social perception and task performance to team preference using individual observer ratings. Figure 2A plots team preference (y-axis) against perceived social ratings (mean z-scored warmth and competence; x-axis), with jitter added for clarity. The fitted line (green) and shaded 95% CI show a positive association, indicating stronger preferences for teams rated higher in warmth and competence. Figure 2B shows the residual effect of task performance after controlling for social ratings, plotting residualized team preference against standardized task performance. The shallower slope indicates that objective task performance had a comparatively weaker influence on participants’ team preferences than social perceptions of warmth and competence.

5 Discussion & Conclusion

In this study, we examined how people perceive warmth and competence in robot swarms by systematically manipulating speed, separation distance, and broadcast duration. Swarm behaviors elicited a wide range of social perceptions, which predicted team preference more strongly than objective task performance.

Our findings extend prior work on social perception of single agents [14, 23, 25, 26, 38] to the swarm level. Consistent with social perception of human groups [10, 11], warmth and competence judgments of robot swarms were shaped by distinct behavioral factors, with competence driven primarily by separation distance and warmth shaped by longer broadcast durations of target sharing. Analysis of post-task questionnaire showed that participants grounded warmth in prosocial collective behaviors, frequently describing “helping,” “information sharing,” “coordination,” “welcoming,” and “not leaving any robot behind,” indicating that warmth reflected perceived cooperative intent rather than superficial visual cues [34]. Moreover, social perception influenced team preference alongside objective performance, suggesting that optimizing solely

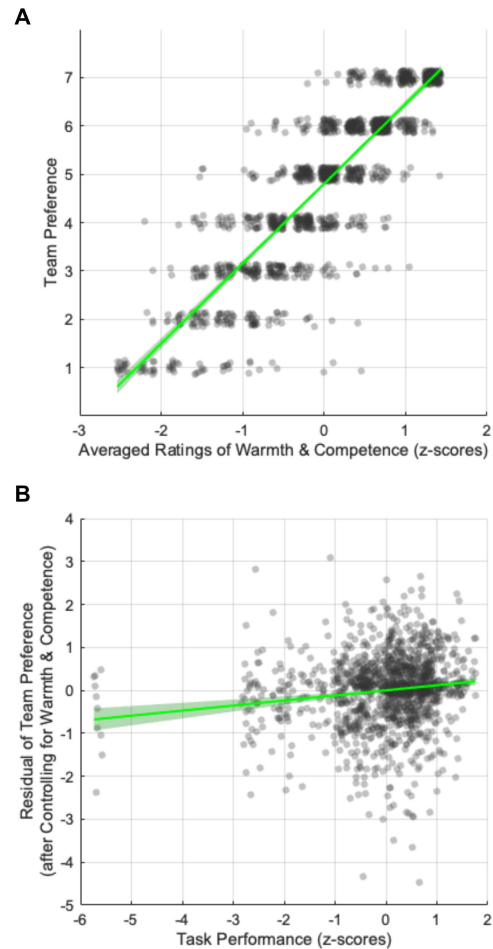


Figure 2: (A) Team preference vs. social ratings (average z-scored warmth & competence). (B) Team preference vs. task performance (after controlling for warmth & competence).

for efficiency is insufficient for effective human–robot collaboration [14, 26, 36, 38]. For example, while speed is often prioritized as a key design parameter in swarm systems [8, 40], our results show that perceived competence is not determined by speed alone. Instead, separation distance emerged as a stronger predictor of competence, as wider spatial coverage enabled earlier discovery and more effective information sharing even at lower movement speeds. This suggests that participants interpreted competence as effective collective coordination among the robots [2] rather than raw velocity. Future research could draw on insights from human social behavior and other natural systems [27, 39] and incorporate established social perception scales (e.g., RoSAS[1], NARS[32]) to provide a more fine-grained, multidimensional assessment of how collective swarm behaviors shape social perception of robot teams.

In summary, our studies show that social perception plays a central role in shaping human preferences for robot swarms, highlighting the need to integrate both technical and social considerations when designing effective human-robot teams.

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