# Implicit Behavioral Cues for Enhancing Trust and Comfort in Robot Social Navigation

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***Abstract*—Robots navigating public spaces must move not only safely, but in ways that are intuitive and socially appropriate. This study investigates how implicit motion cues—such as slowing down or adjusting trajectory—affect pedestrian comfort, trust, and clarity of intent. Using a TurtleBot4 and a Wizard-of-Oz setup, we tested five behaviors: no cue, sudden stop, speed reduction, curved trajectory, and verbal announcement. In hallway encounters with 15 participants, we collected subjective ratings and video analysis of pedestrian behavior. Results show that trajectory-based cues significantly improve perceived comfort and trust, while abrupt or neutral behaviors lead to discomfort and hesitation. These findings highlight the importance of implicit motion cues for legible and socially aware robot navigation.**

***Index Terms*—Social navigation, human-robot interaction, implicit communication, trust in robotics, robot legibility**

## I. Introduction

As robots enter public spaces like hallways and intersections, their ability to navigate around humans in a socially acceptable manner becomes critical for building trust and enabling broader adoption [1], [2]. In particular, brief navigation encounters—where a robot and pedestrian cross paths—demand behaviors that are not only safe but also interpretable and comfortable for humans.

*Social navigation* involves robots moving in human environments in ways that are legible and respectful of social norms [1]. Beyond avoiding collisions, trust depends on whether pedestrians can predict the robot's behavior and feel safe [2]. Studies show that legible motion patterns can improve trust [3], especially when intent-expressive actions are visible to observers [4]. Evaluating such behavior requires multi-dimensional assessment frameworks [5].

To convey intent, robots typically rely on *explicit* cues (e.g., speech, lights) or *implicit* motion-based behaviors (e.g., speed, trajectory, proximity). While explicit signals are easy to interpret, they rely on attention and may be missed in dynamic settings [2]. Implicit cues are especially important for non-humanoid robots, which lack the ability to use gestures like humanoid robots. These cues are embedded in motion and can communicate intent subtly, but require careful design to be effective.

Prior work shows that legible motion and spatial cues improve coordination, especially when actions are visible from a pedestrian's viewpoint [3], [4], [6]. However, many existing studies often relied on simulations or video studies to evaluate social navigation behaviors [3], [4], limiting real-world applicability. Our study addresses this by comparing five cue types, analyzing subjective ratings and pedestrian behavior, and conducting a real-world hallway experiment using a TurtleBot4 platform.

We aim to answer: *How can robots use implicit behavioral cues to improve pedestrian comfort, trust, and safety during navigation encounters?*

## II. Experimental Design

We conducted a hallway navigation study where 15 participants walked toward a TurtleBot4 robot exhibiting one of five cue behaviors:

- **No Cue**: Default navigation (e.g., as used in Nav2) with no human-specific signaling.
- **Sudden Stop**: Abrupt stop at close range, mimicking conservative collision avoidance behavior.
- **Speed Cue**: Gradual slowdown, signaling awareness of the pedestrian.
- **Trajectory Cue**: Curved approach to indicate passing side and respect personal space.
- **Explicit Cue**: Verbal message (e.g., "Passing on your left") via onboard speaker.

These five cues range from socially unaware (No Cue, Sudden Stop) to implicit (Speed, Trajectory) and explicit signaling (Verbal). Each participant experienced all five conditions in randomized order. A *Wizard-of-Oz* protocol ensured consistent behavior across trials, with the robot teleoperated using ROS2 to control trajectory shaping and speed modulation.

### A. Data Collection

We recorded both subjective and behavioral data:

- **Subjective ratings**: comfort, trust, predictability, clarity, and proxemics, collected via 5-point Likert surveys after each trial.
- **Behavioral analysis**: hesitation time, crossing duration, passing distance, and trajectory (via video analysis).

### B. Expected Behavioral Effects

We hypothesize that each cue will elicit distinct pedestrian responses. In the *No Cue* condition, the robot's default obstacle avoidance may appear unpredictable, leading to hesitation or perceived invasion of personal space. *Sudden Stop* may also increase hesitation and frustration due to its abrupt and reactive motion. *Speed Cue*, by slowing near the pedestrian, is expected to enhance perceived safety and control—similar to how vehicles yield at crosswalks. *Trajectory Cue* should result in smoother, more confident interactions by signaling passing side early and respecting social distance. While *Explicit Cue* conveys intent clearly, it may momentarily confuse some participants who must interpret directionality (e.g., "your left") from the robot's perspective.

## III. Results

We analyzed how different robot behaviors influenced pedestrian perception and response during hallway encounters, using both subjective ratings and behavior analysis.

### A. Subjective Ratings

Participants rated each cue on five metrics: *comfort*, *trust*, *predictability*, *clarity*, and *proxemics*. The Trajectory Cue received the highest average ratings across all dimensions, followed by Speed Cue and Explicit Cue. In contrast, Sudden Stop and No Cue received the lowest ratings, particularly in predictability and proxemics (Fig. 1).

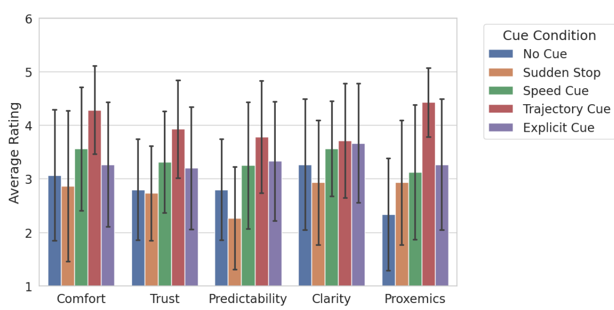


Fig. 1. Average participant ratings across cue conditions (1 = Strongly Disagree, 5 = Strongly Agree).

### B. Statistical Analysis

Repeated measures ANOVA revealed significant effects of cue condition on most subjective metrics ($p < 0.05$), except clarity. Post-hoc tests (Holm-corrected) showed that Trajectory Cue significantly outperformed *No Cue* and *Sudden Stop* in comfort, trust, and proxemics. *Speed Cue* was rated higher than *Sudden Stop* in comfort and predictability. These results highlight the value of implicit motion cues for conveying intent.

### C. Behavioral Analysis

Video analysis showed that the Trajectory Cue enabled the smoothest interactions, with minimal hesitation and shorter crossing times. In contrast, Sudden Stop introduced uncertainty, and No Cue led to inconsistent and cautious pedestrian behavior.

As illustrated in Fig. 2, the No Cue condition caused participants to change direction abruptly (blue circle) and maintain visual focus on the robot (blue arrow), indicating higher cognitive load and reduced trust. Sudden Stop led to noticeable pauses (orange circle), while Speed Cue allowed for early decisions and smooth paths (green circle). Trajectory Cue effectively signaled intent with a curved path, prompting natural, comfortable detours (red circle). In the Explicit Cue condition, pedestrians sometimes had to adjust their route when the robot's stated intent did not match their preference (purple circle) and often continued monitoring the robot to ensure follow-through (purple arrow). A detailed visualization of pedestrian behavior for all conditions is in Appendix A.

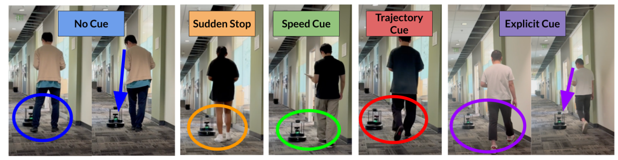


Fig. 2. Illustration of pedestrian responses across different cue conditions.

Participant feedback echoed these findings: *"Even when it told me the direction, I couldn't figure out if it was going to give me space or not,"* and *"Alert could be sooner, redirection could be sooner."* These responses highlight the value of early, spatially meaningful cues in fostering trust and clarity during navigation.

## IV. Discussion

Our results suggest that even simple motion-based cues, such as slowing down or curving the trajectory, can significantly improve how pedestrians perceive robot behavior in shared spaces. These implicit behaviors serve as intuitive and lightweight signals of intent, enhancing trust, comfort, and perceived safety without requiring explicit communication. This highlights the broader importance of designing robot navigation not only for collision avoidance, but also for social legibility and human interpretation.

Our findings generally aligned with the anticipated effects of each cue. Trajectory Cue promoted smooth and confident passing behavior as expected, and was rated highest in comfort and trust. Speed Cue gave participants more time to react, supporting its role in enhancing perceived control. Sudden Stop and No Cue led to more hesitation and awkward rerouting, consistent with concerns about unclear or abrupt behavior. Explicit Cue also performed well, though some hesitation aligned with our hypothesis that verbal directionality might require additional cognitive processing. A detailed breakdown for each cue can be found in Appendix B.

## V. Conclusion

This study demonstrates that implicit motion cues can meaningfully improve pedestrian comfort and trust during brief robot encounters in shared spaces. Our findings highlight the value of designing robot behaviors that are not only safe but also socially legible and intuitive. Future work will build on these findings by applying social navigation strategies to *robot-human teams*, such as robot guide dogs that must navigate collaboratively with or on behalf of users. Additionally, we will evaluate the identified cues across *larger and more diverse participant groups* to assess generalizability across demographics and cultural norms. Finally, we will integrate effective motion cues into *autonomous navigation algorithms* and explore their potential inclusion in safety and behavior standards for socially aware robots.

## References


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## Appendix A
## Visualizations of Pedestrian Behavior Across Cue Conditions

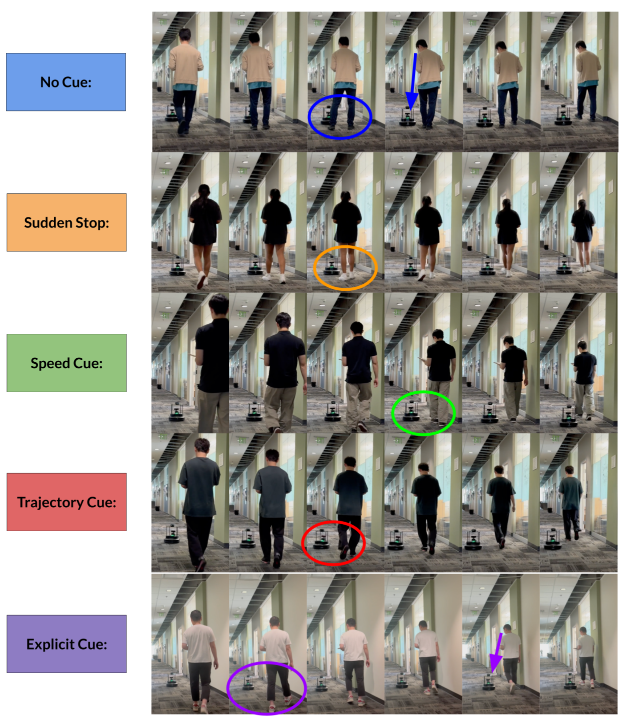


Fig. 3. Full visualization of pedestrian responses across all cue conditions.

## Appendix B
## Comparison with Expected Behaviors

As expected, the Trajectory Cue received the highest ratings across all subjective dimensions, supporting the hypothesis that curved paths resembling human motion foster intuitive and respectful navigation. Participants likely appreciated the early indication of passing side and the preservation of personal space, consistent with natural human-human avoidance strategies.

The Speed Cue also performed well, particularly in comfort and trust, aligning with our expectation that slowing down gives pedestrians more time to assess and choose their response. This cue likely conveyed a sense of caution and awareness, similar to how drivers slow down near pedestrians.

Surprisingly, the Explicit Cue, while clear in its intent, did not outperform the Trajectory Cue. Although we expected high clarity, participants may have hesitated due to the need to cognitively process directional language (e.g., "Passing on your left") and match it to their own perspective, confirming our concern that explicit verbal cues may introduce brief confusion.

The Sudden Stop condition was rated lowest in predictability, as hypothesized. Its abruptness may have disrupted participants' sense of natural flow and increased uncertainty or frustration during interaction. Finally, No Cue scored lowest in proxemics, confirming our expectation that default navigation lacks social awareness and may be perceived as invasive or indifferent to personal space.

Overall, the results validate the role of implicit cues—particularly trajectory and speed—in fostering trust, comfort, and clarity during brief human-robot encounters in shared spaces.