THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

Signaling Human Intentions to Service Robots: Understanding the Use of Social Cues during In-Person Conversations

Hanfang Lyu[1], Xiaoyu Wang[1], Nandi Zhang[2], Shuai Ma[1], Qian Zhu[3], Yuhan Luo[4], Fugee Tsung[1,5], and Xiaojuan Ma[1].

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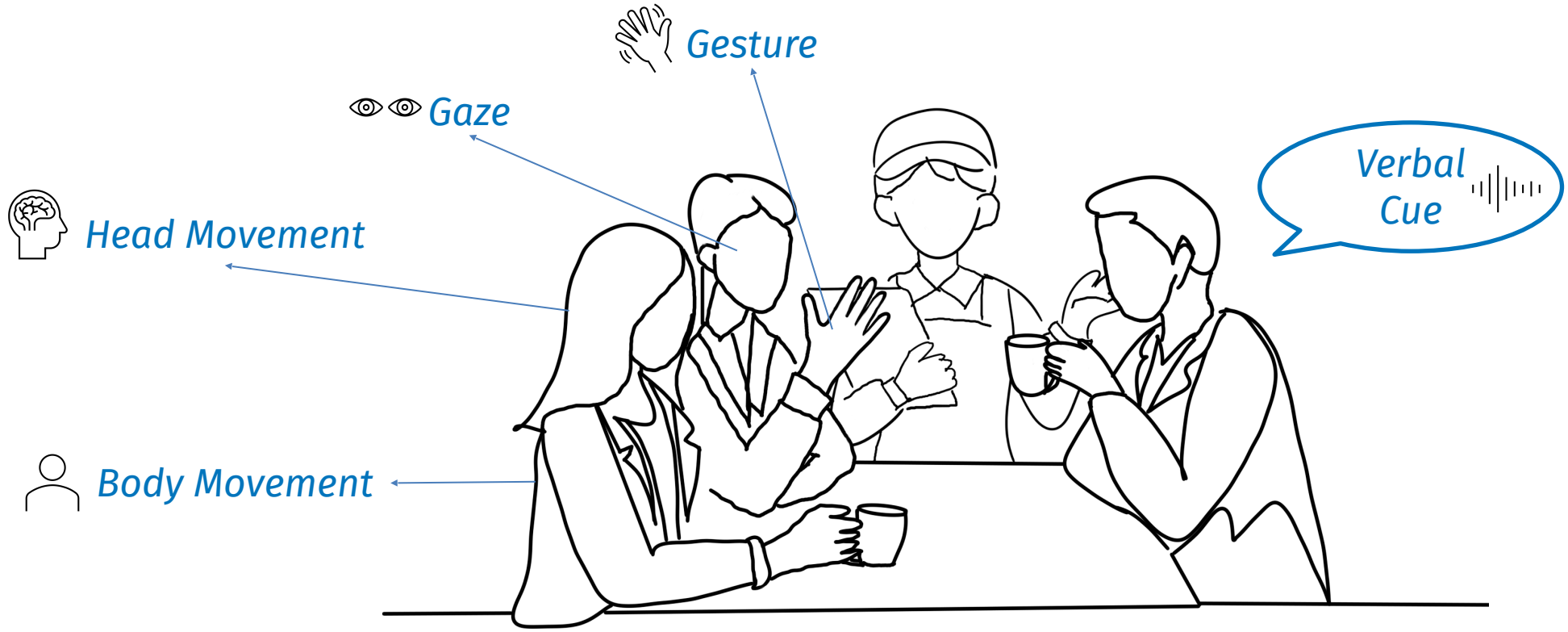
Human use different social cues every day

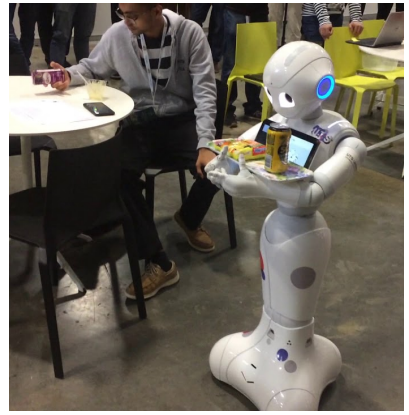
During in-person conversations, people naturally employ different modalities of social cues to communicate their intentions.



Service Robot in Social Settings

- Service robots in retail, healthcare, hospitality, etc.
- Serving during *human-human interactions* (HHI)

Aliengo
https://youtu.be/CaH-SSKAIe4?si=ZH0gik_RAIhWV11K&t=7



Pepper
https://youtu.be/KzwHOufMT_A?si=uC1XoMWu7SqLdh8b&t=56

Drone
https://www.techinasia.com/singapore-restaurant-autonomous-drone-waiters

BellaBot
https://youtu.be/_kDj3PEm6aw?si=SIFz7jsa69xu114w&t=22

Service Robot in Social Settings

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Understanding how human signal intentions to different forms of service robots, when primarily engaged in an important social encounter (HHI)

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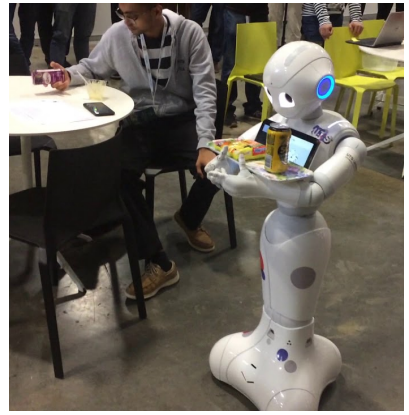

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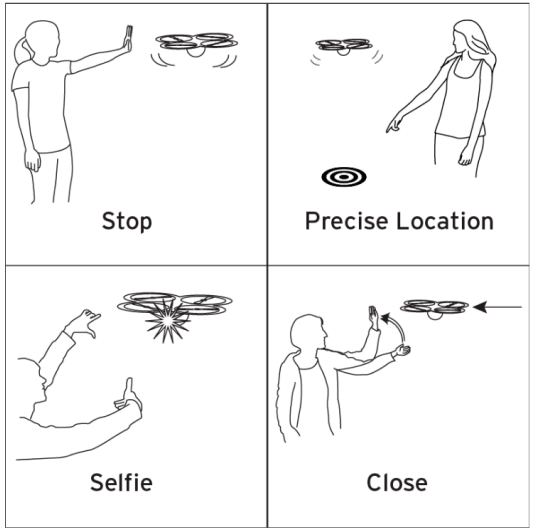
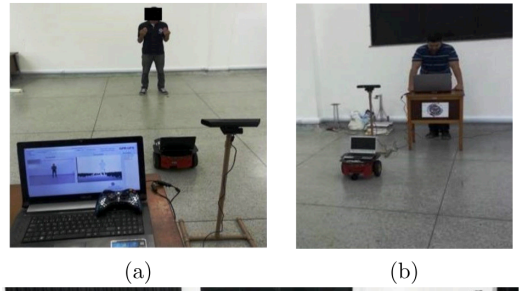
Social Cues Understanding in HRI



Gesture and sound, drone
(Cauchard et al., 2015)

Multi-modality, wearable robotic arm
(Muehlhaus et al., 2023)

Gesture, drone
(Firestone et al., 2019)



Gesture, mobile robot
(Canuto et al., 2022)

Lack a systematic understanding of human *social cue* interaction with *social service robots*

- Including a wide range of social cue **modalities**
- Comparing multiple **robot forms**
- From lab-based settings to **real-world** social scenarios

Research Questions

How humans choose and combine different modalities of social cues to signal different intentions to **a service robot** during **an engaging social encounter**?

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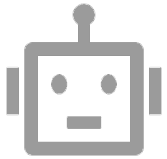

How different **robot morphologies** influence the use of social cues?

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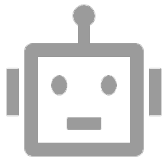


How different **robot morphologies** influence the use of social cues?

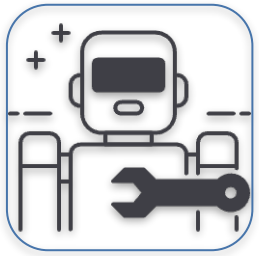
How different **human engagements in the HHI** influence the use of social cues?

Contribution

We contribute insights from An Elicitation Study on human signaling robot waiters during an important coffee chat to better understand

Usage of social cues

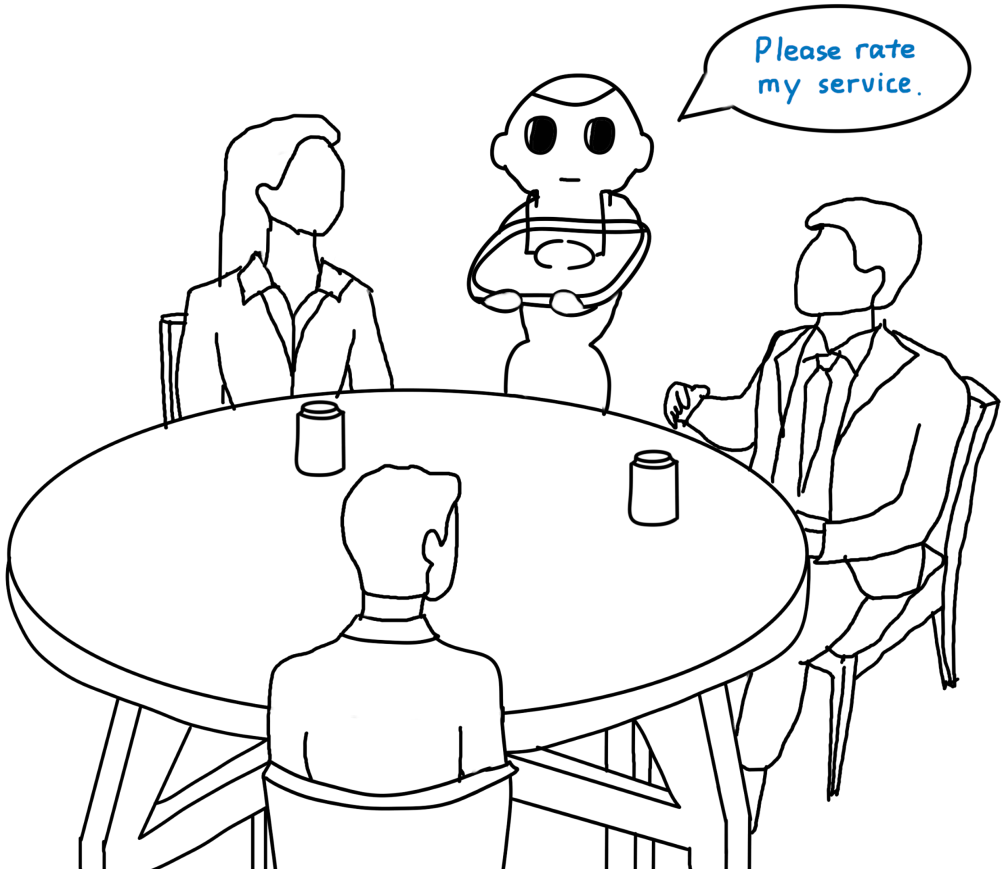
Influencing factors and rationales



Design implications

Experiment Simulation: Social Encounter

- Coffee chat with *potential employers*



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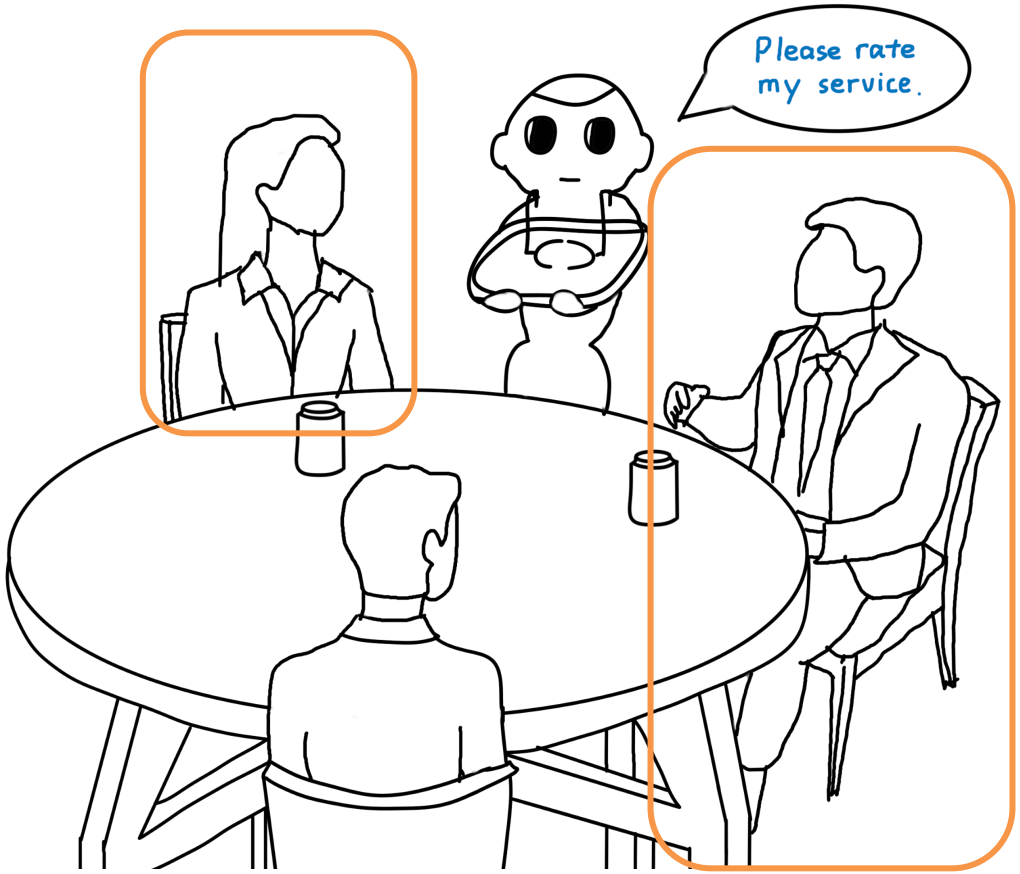
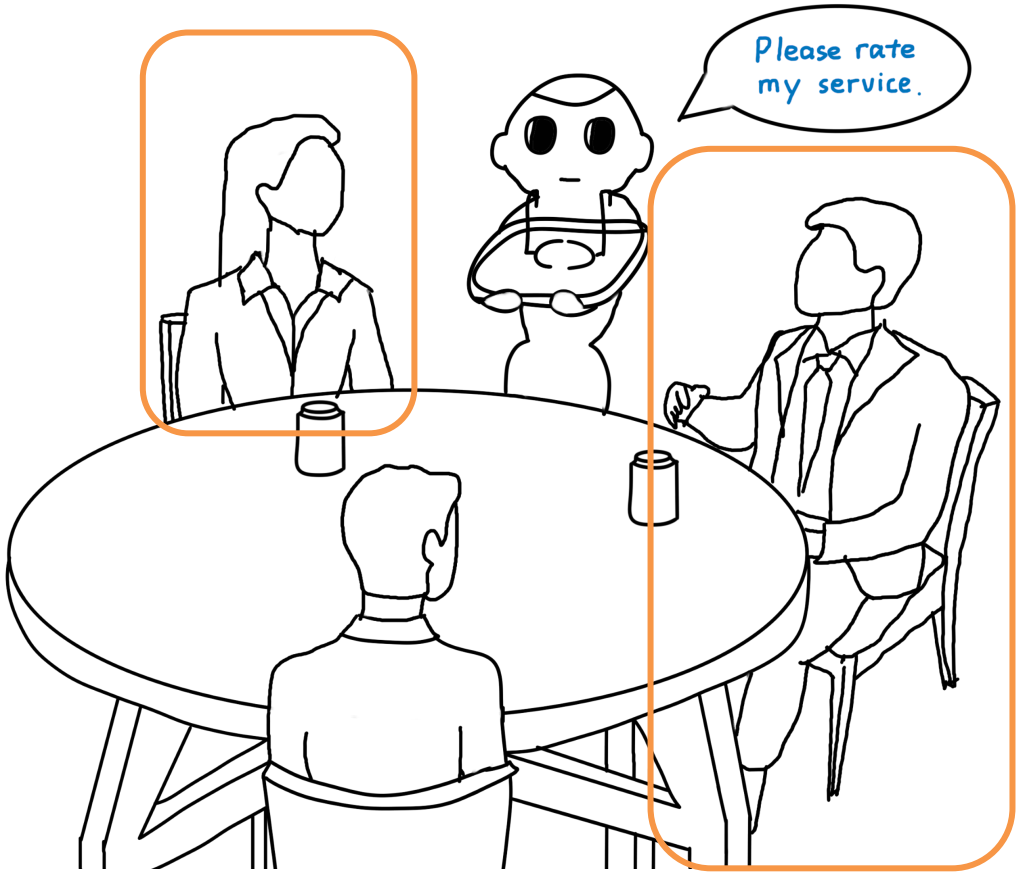


Two actors trained to play the roles of two potential employers

Experiment Simulation: Social Encounter

- Coffee chat with *potential employers*
- ***ConversationRole***



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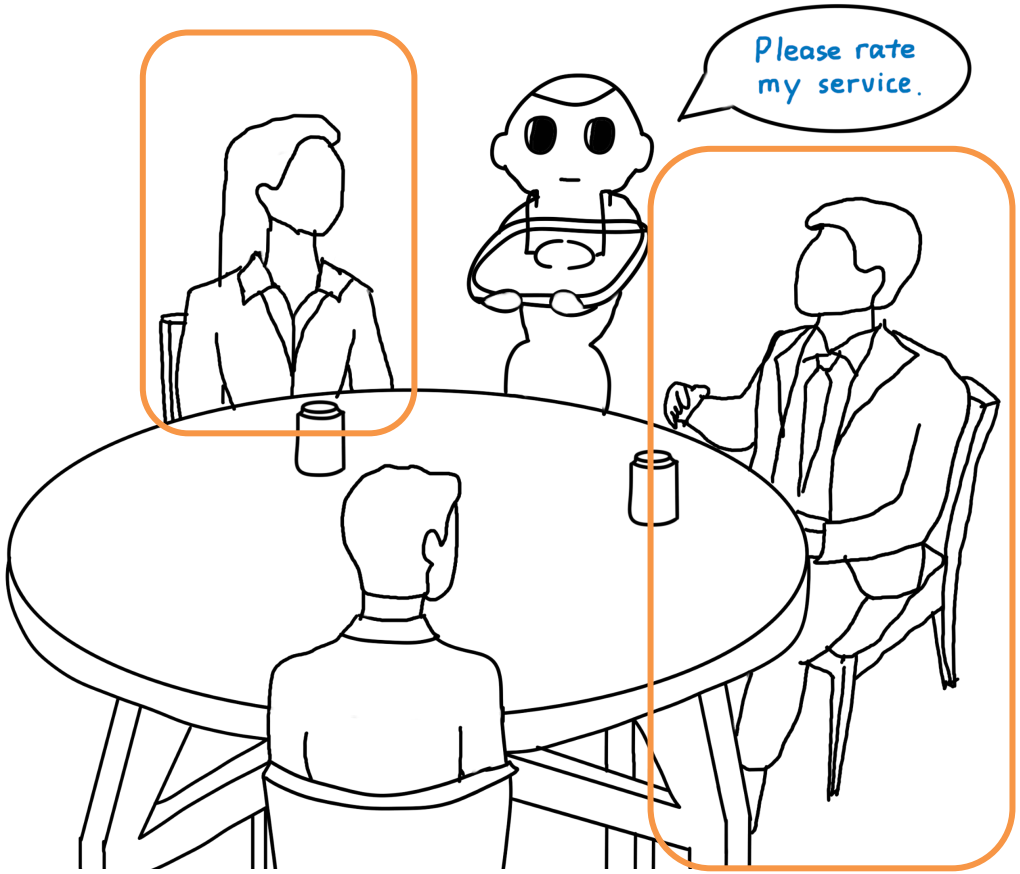

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  - *speaker* (participants lead the conversational flow)
  - *listener* (participants listen to the conversation lead by others)

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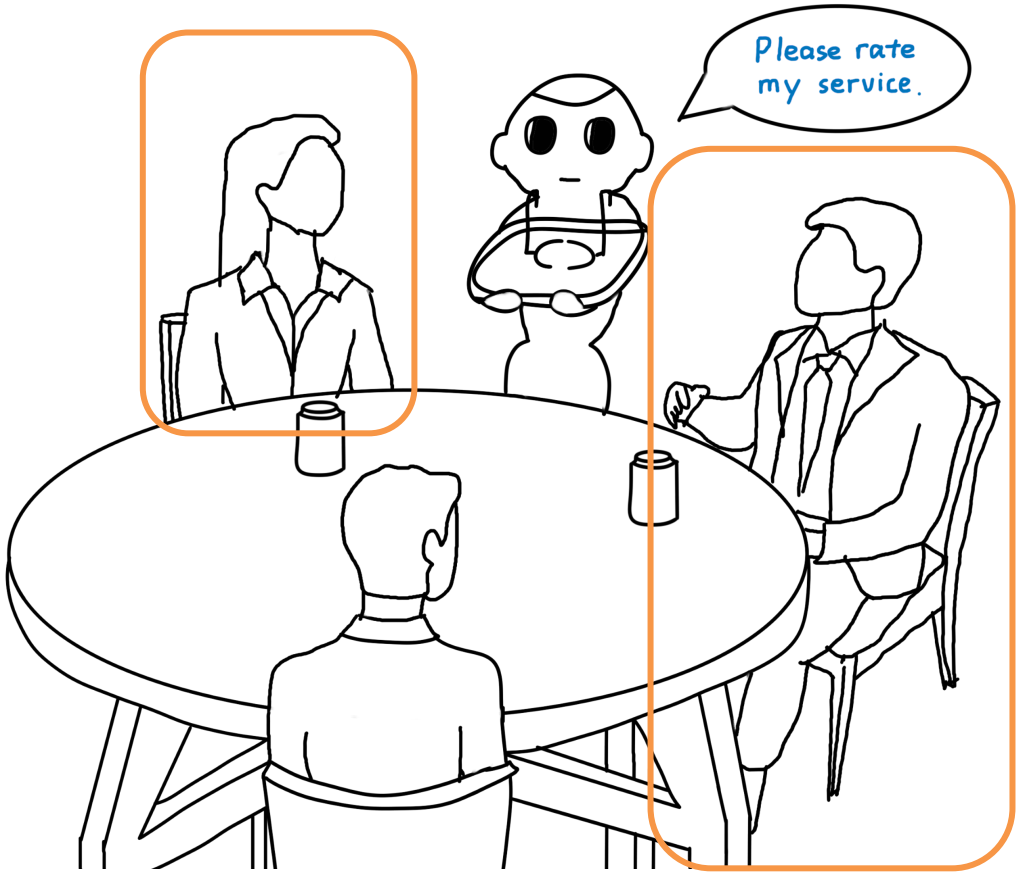

Experiment Simulation: AR Simulated Robot

- ***RobotMorphology*** (Onnasch and Roesler, 2021)

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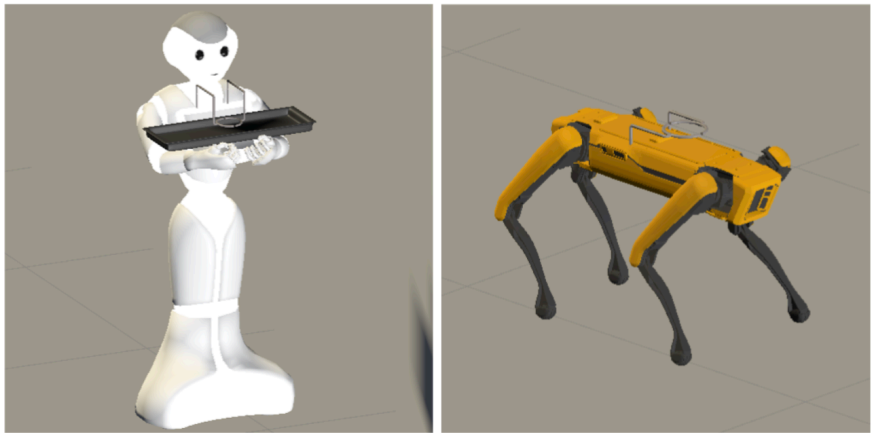

(a) Anthropomorphic Robot

(b) Zoomorphic Robot

(c) Grounded Technical Robot

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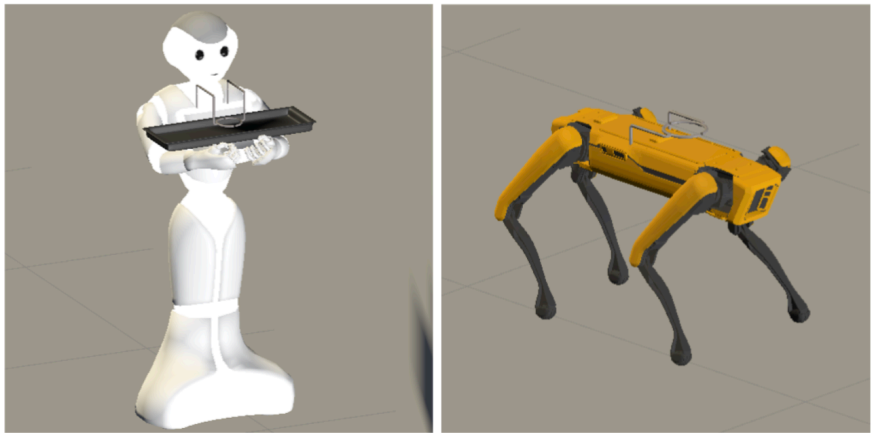

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  - *Anthropomorphic* → Pepper

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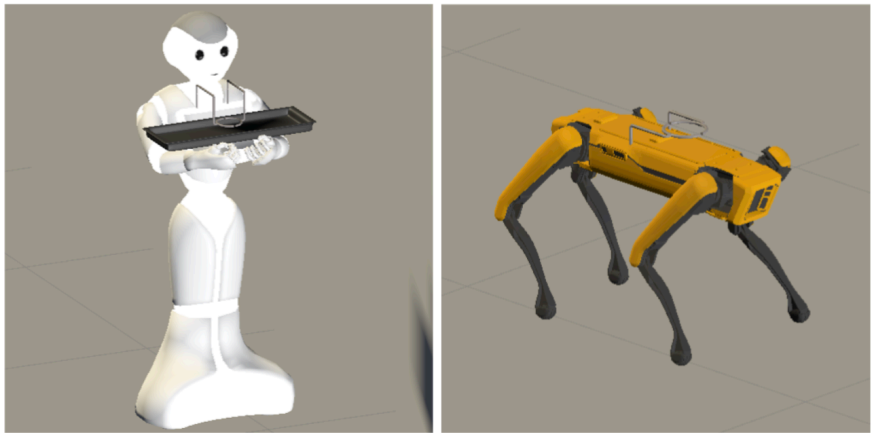

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Elicitation Referents

5 Necessary HRI Types in Social Settings -> 13 interaction referents in the scenario

Robot *Active* Seeking for Human Input	i. When the robot is not sure	
	ii. When the robot asks for evaluation	
	iii. When the human signals awareness	
Robot *Passive* Receiving Human Input	When the robot has an error	iv. Performance error
		v. Social error

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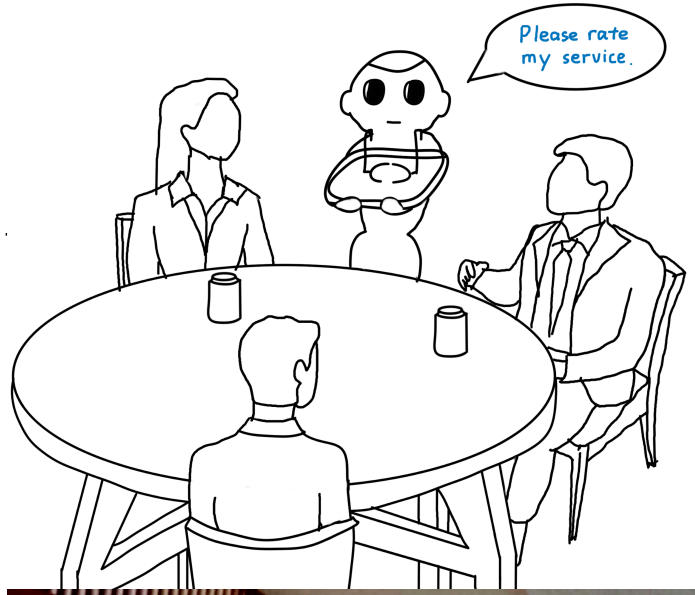

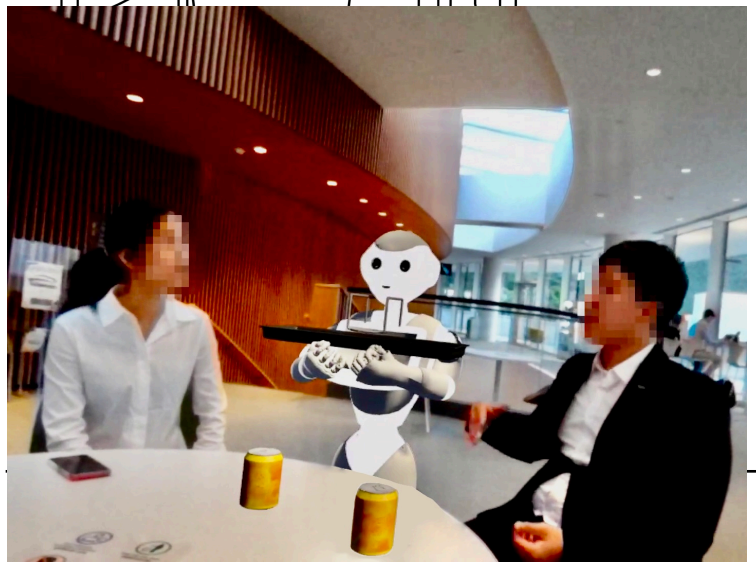

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Elicitation Study

ConversationRole:

listener + speaker

24

Each participant

2 sessions:

- ***RobotMorphology***
  (mixed-designed variable, counter-balanced)
- ***ConversationRole***
  (within-subject variable)

× 13 ***Referent***

RobotMorphology:

anthropomorphic 12

zoomorphic 12

grounded technical 12

aerial technical 12

- retrospective think-aloud
  → *explicit* cues
- semi-structured interview

× 24 participants
× 2 sessions
× 13 referents
= 624 social cues

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Data Analysis: social cue coding

1. Iterative social cue coding: by **Modality** (gesture, verbal, eye, head, upper body, leg and foot)

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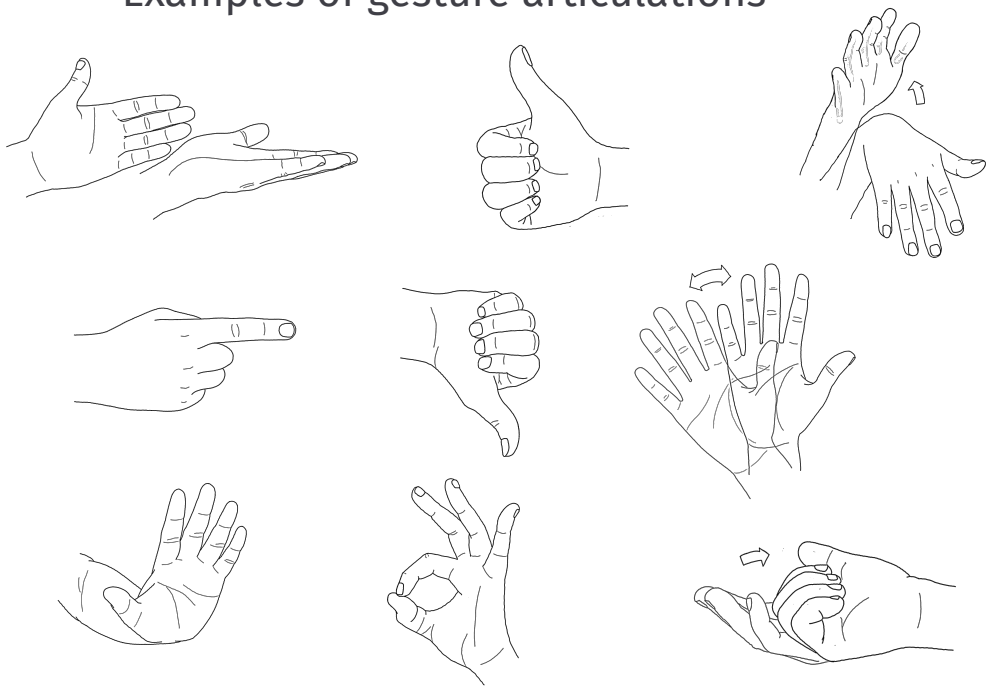
   - Articulation codes: social cue elements

3387

   - Verbal: *exact content, speech act*
   - Examples of gesture articulations



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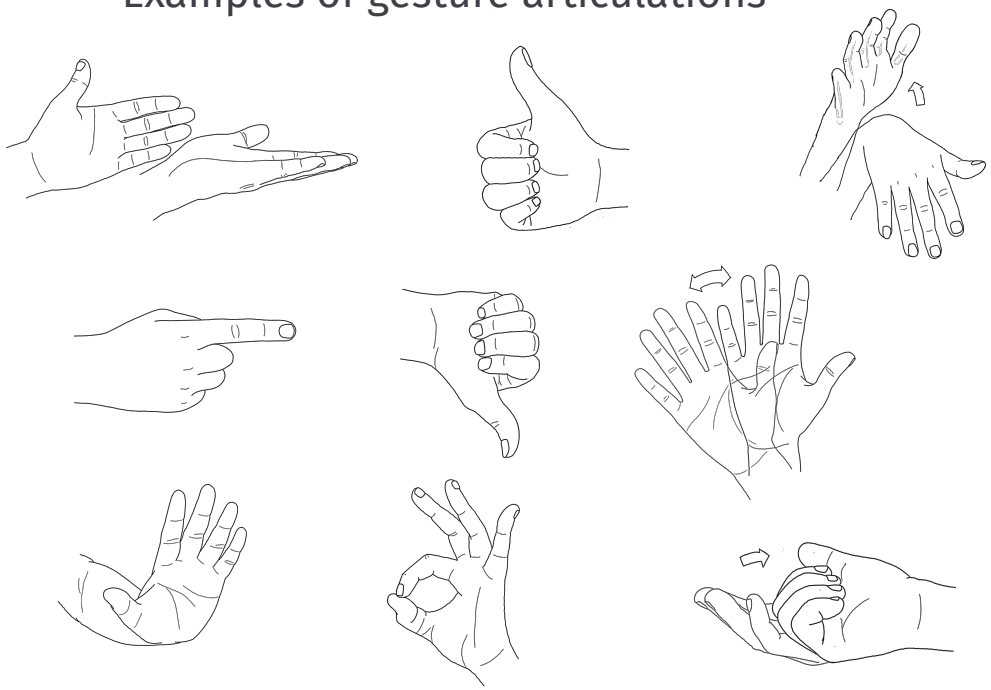

- Feature codes: social cue characteristics
  - Gesture 3318
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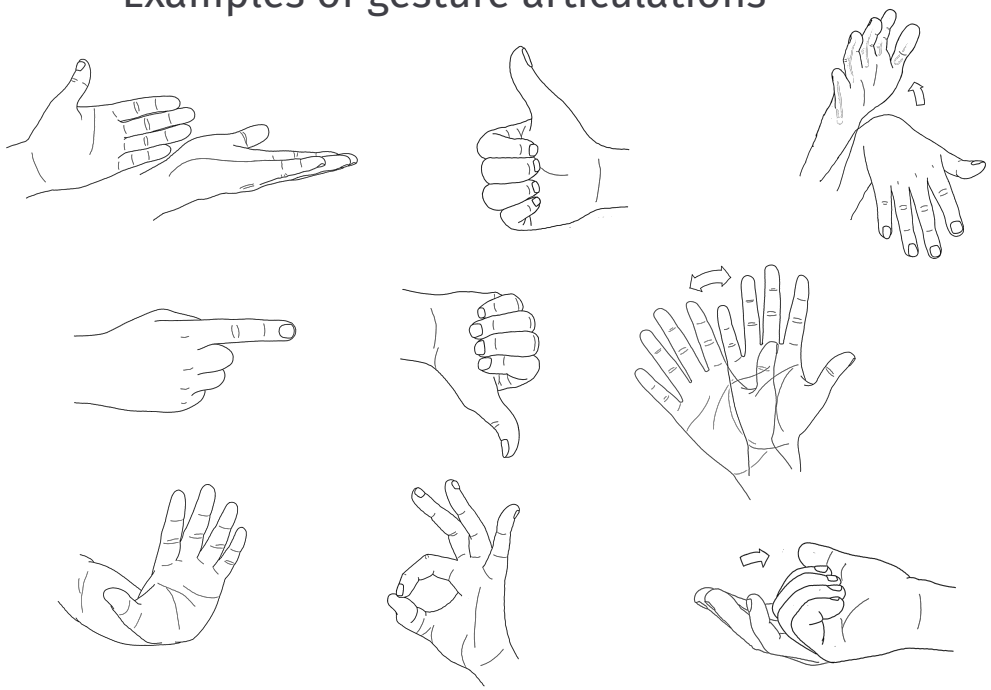

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Explicit Cues: reported during interview
Implicit Cues: observed but not reported
Observed Cues: Explicit + Implicit Cues

Data Analysis: agreement, statistical and interview

2. Agreement Rate

$$AR(r) = \frac{|P|}{|P| - 1} \sum_{P_i \in P} \left(\frac{|P_i|}{P} \right)^2 - \frac{1}{|P| - 1}$$

- $AR \leq 0.1$ for low agreement
- $0.1 < AR \leq 0.3$ for medium agreement
- $0.3 < AR \leq 0.5$ for high agreement
- $AR > 0.5$ for very high agreement

3. Cumulative Link Mixed Model:

forward selection of the following terms

$$Y(Modality\ or\ Feature\ Codes) \sim$$

$$ConversationRole + RobotMorphology$$

$$+ ConversationRole \times RobotMorphology$$

(with *participants nested within Referent* treated as random effect)

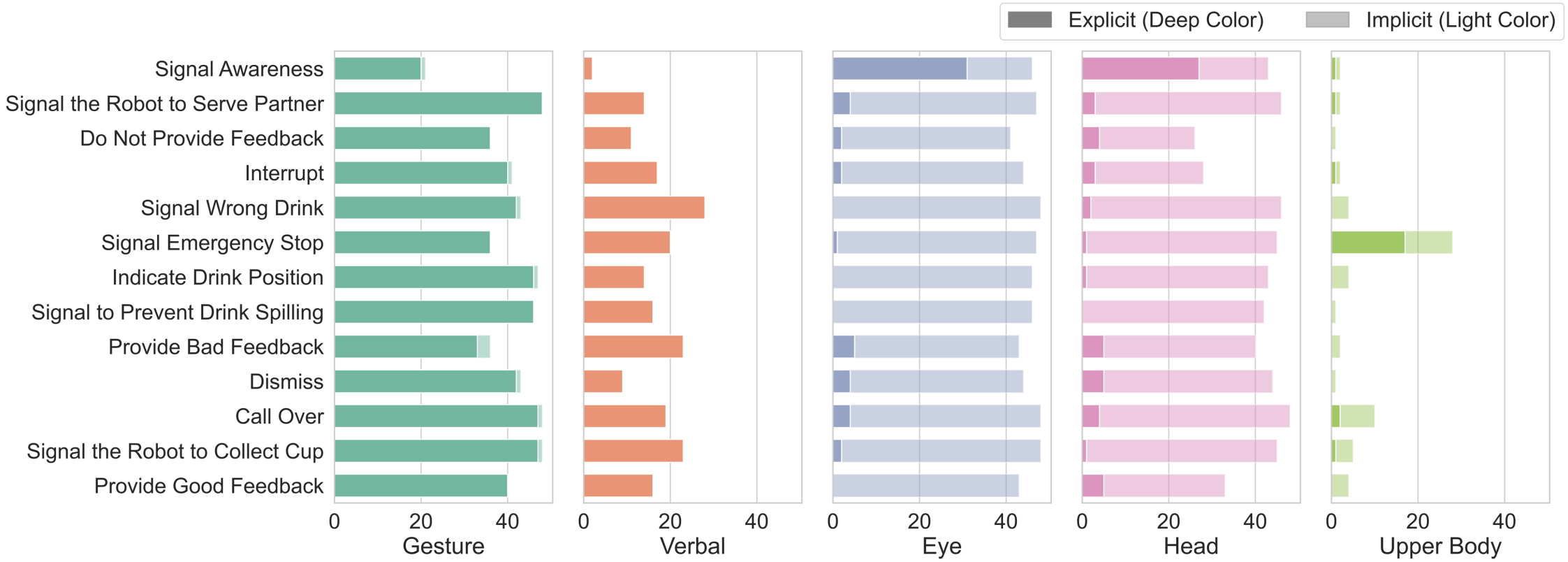
4. Interview analysis: Thematic and iterative analysis

Findings and Discussions

- Social Cue Patterns and Semantics
- Perception on Robots Shapes Interaction Behaviors
  - Perceived Capabilities
  - Perceived Safety
  - Perceived Intelligence
- Primary Task and Social Context Matters

Check our paper for analysis details

Modality Distribution by Referent



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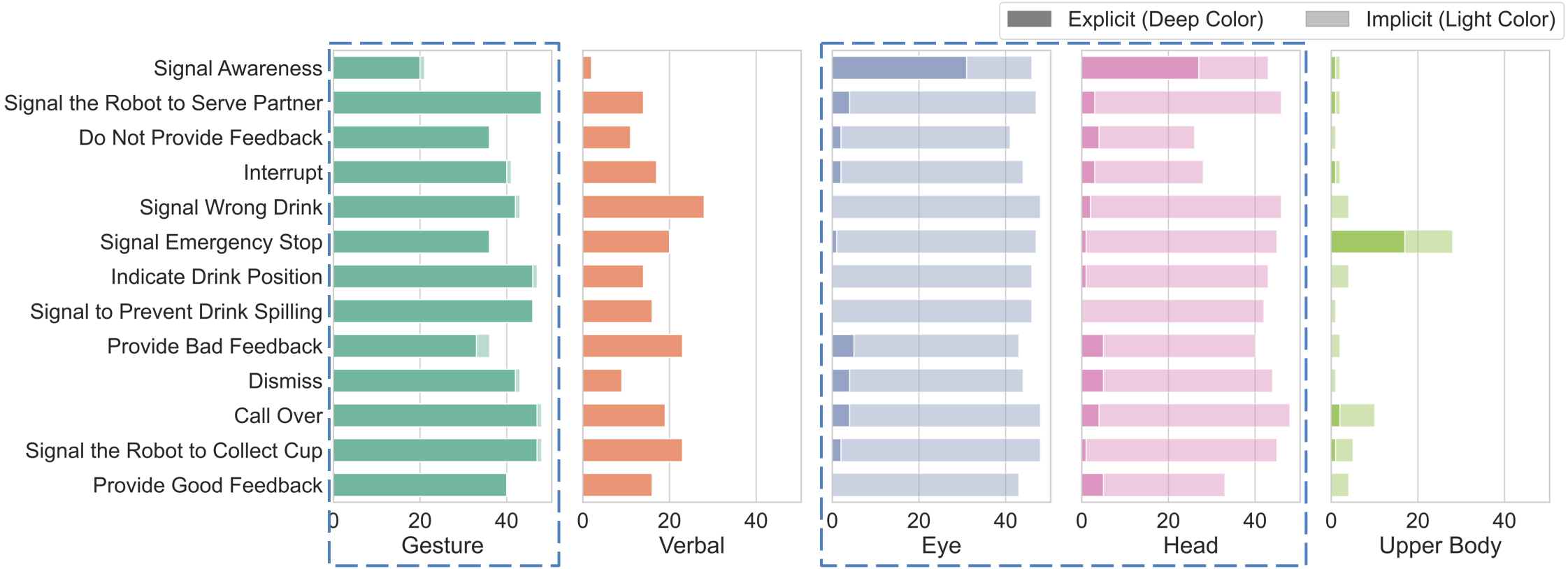

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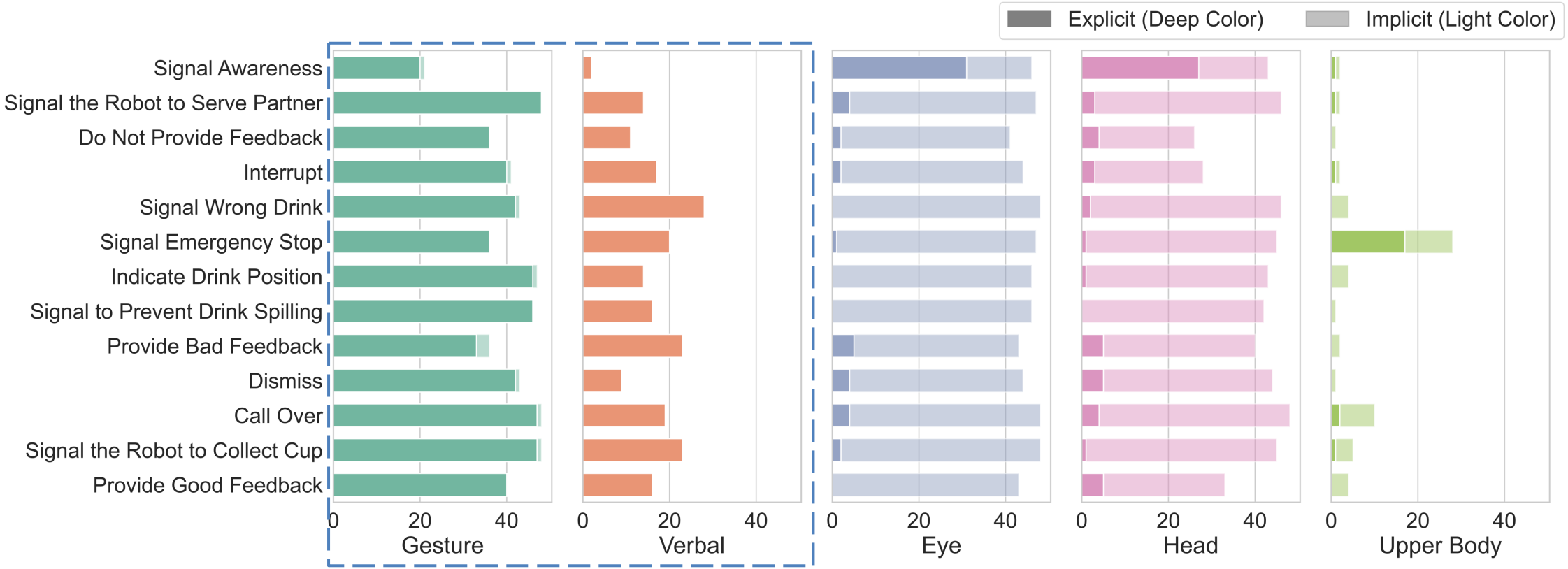

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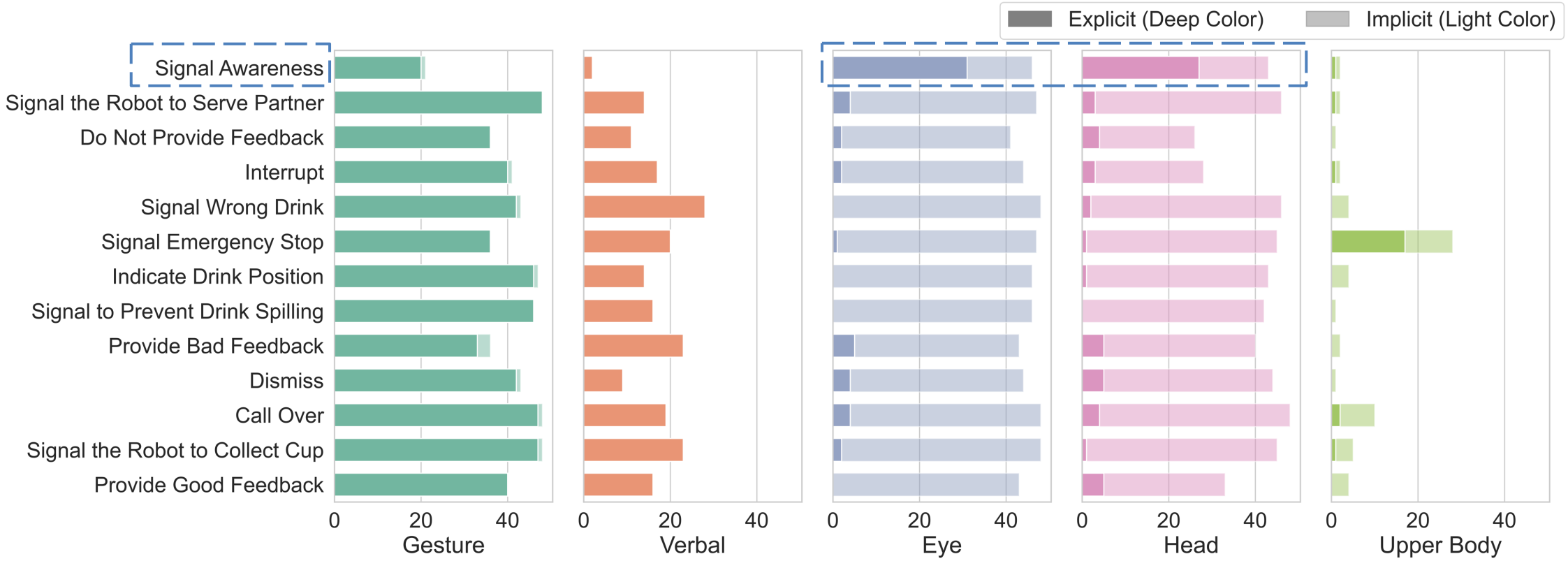

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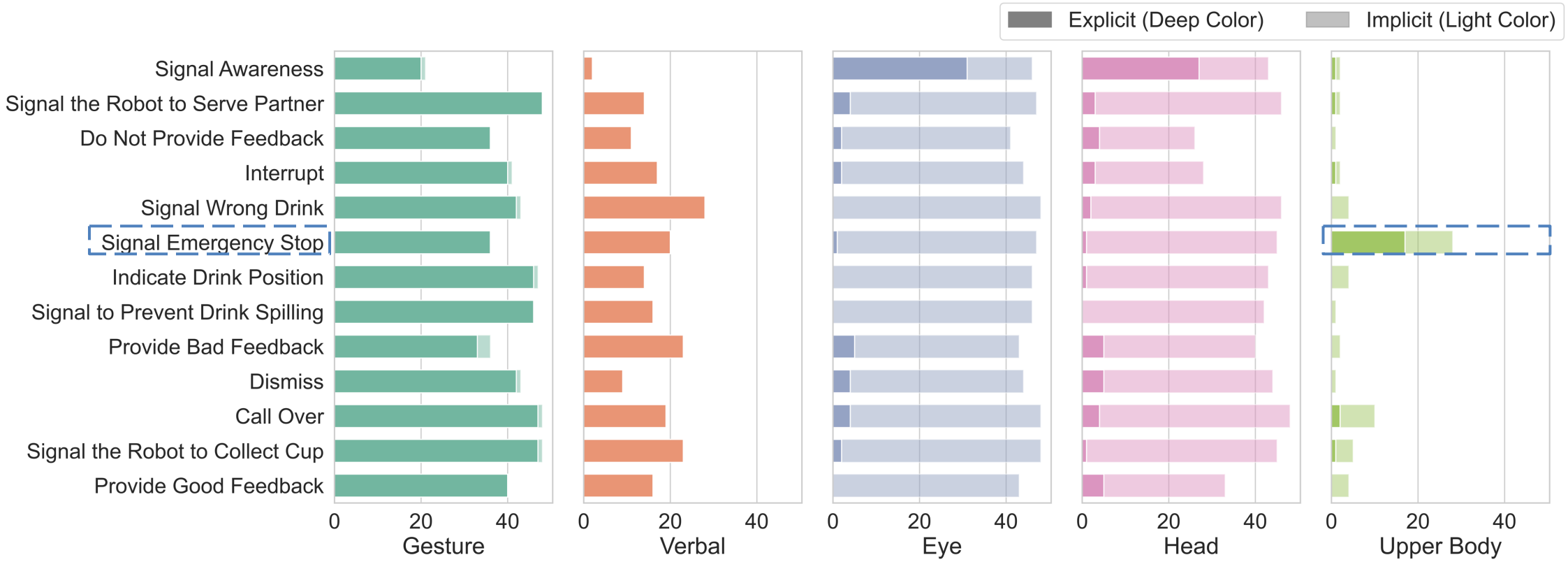

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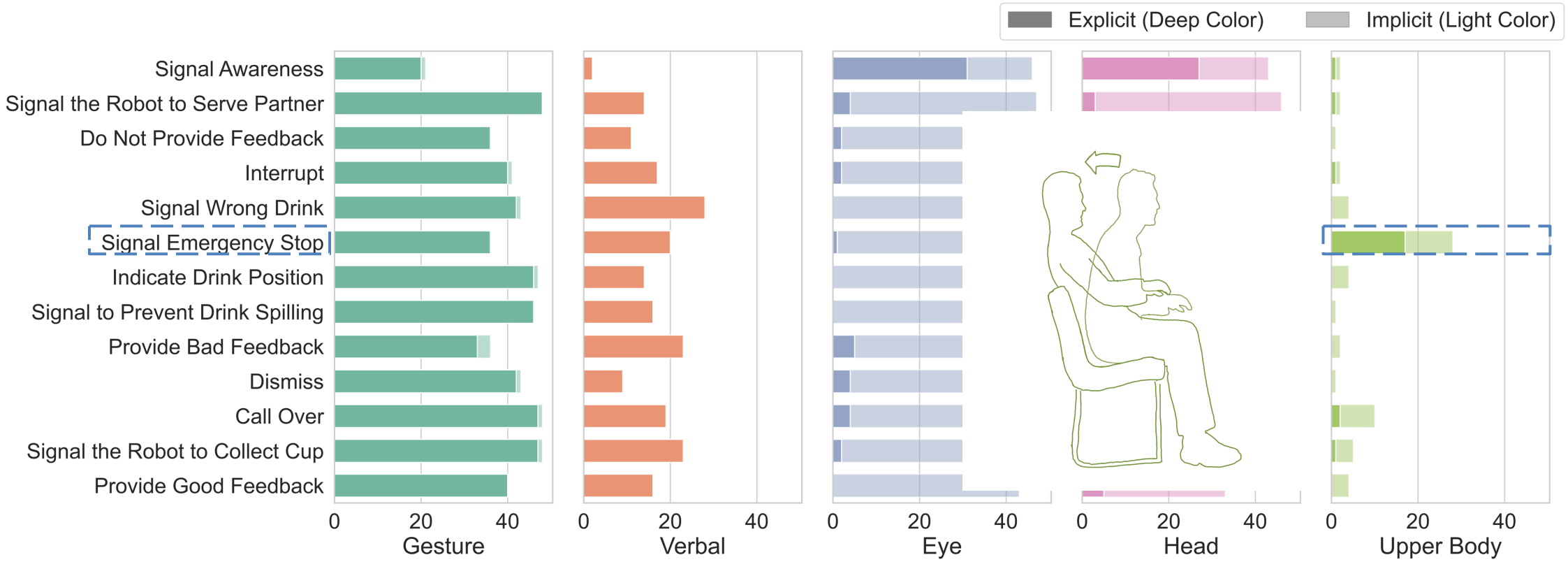

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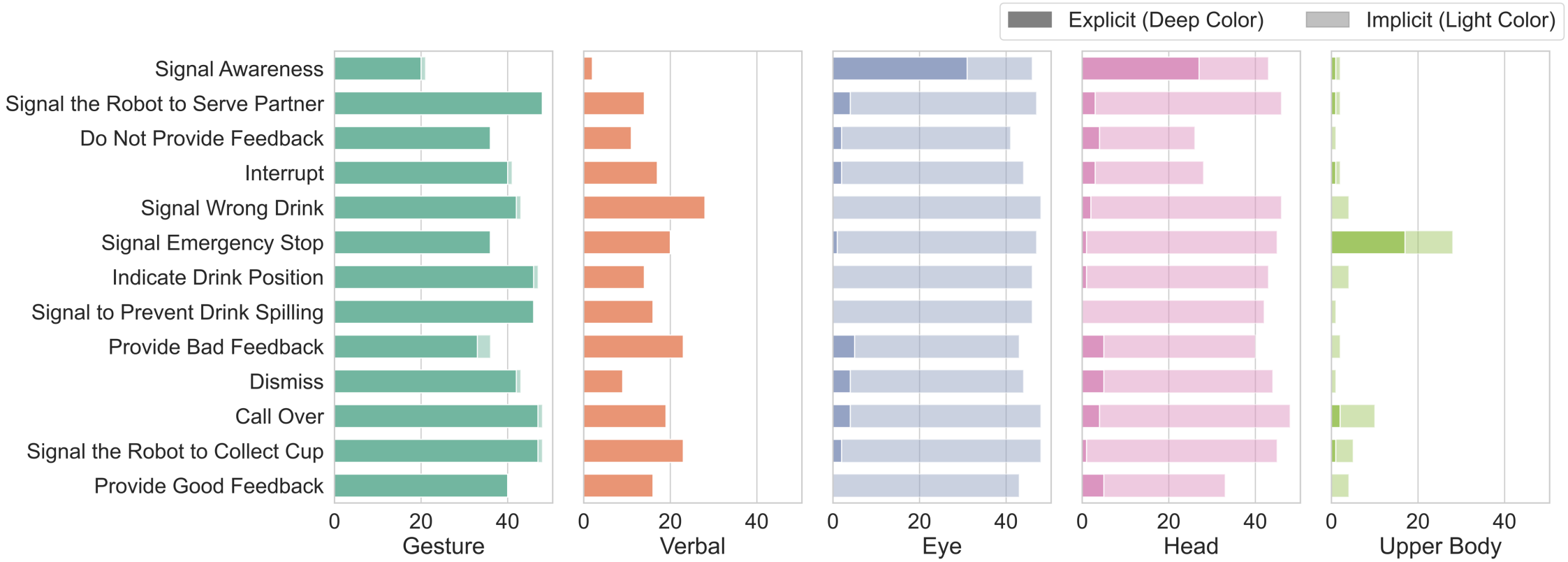

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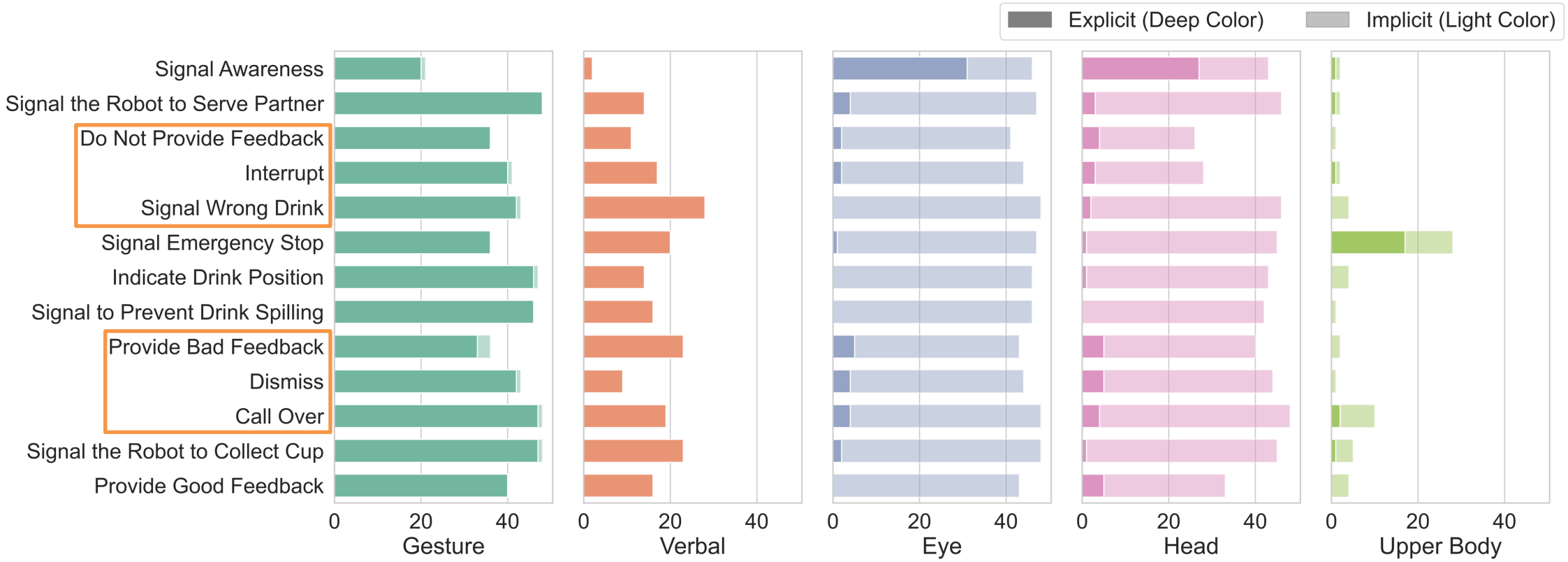

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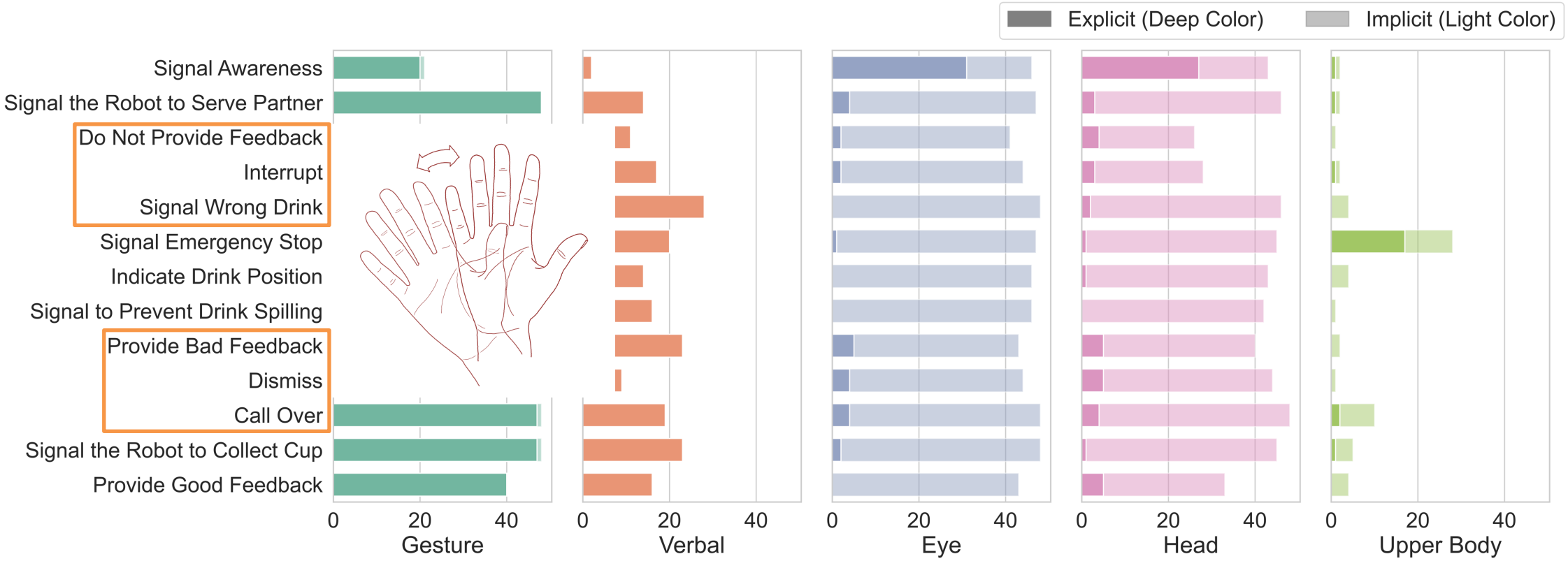

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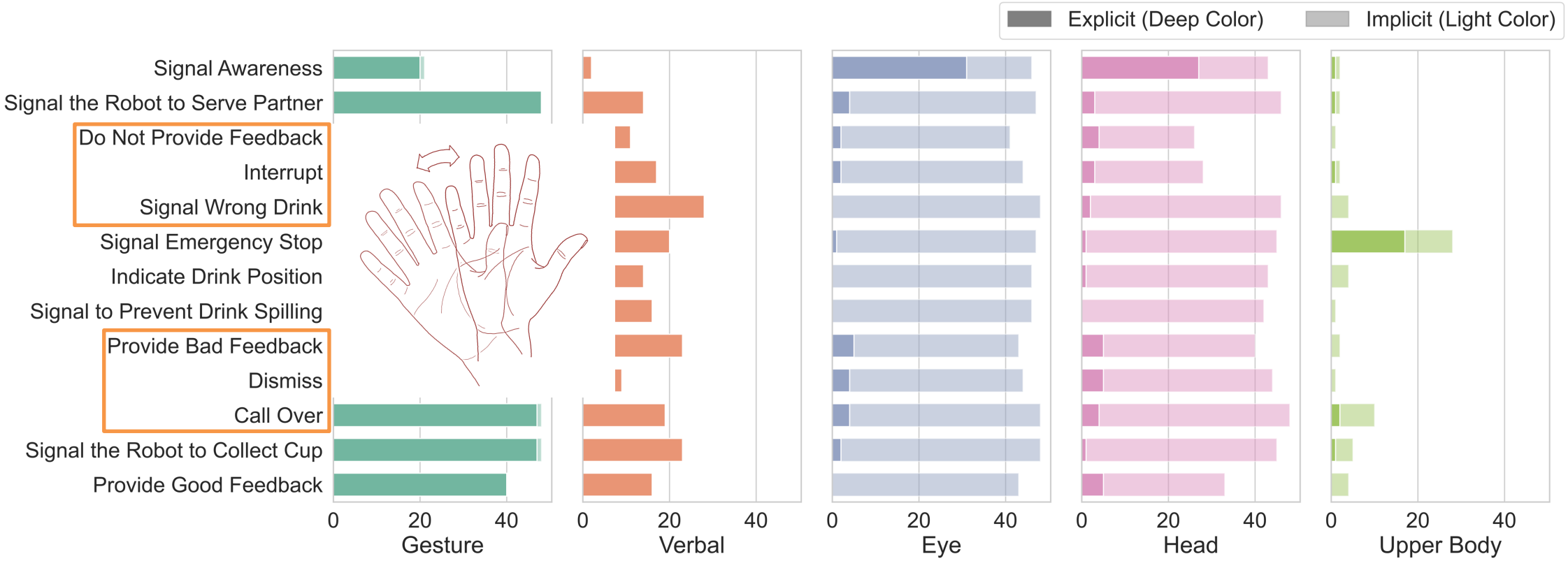

Similar *explicit cues* for different intentions → implicit cues + context to disambiguate

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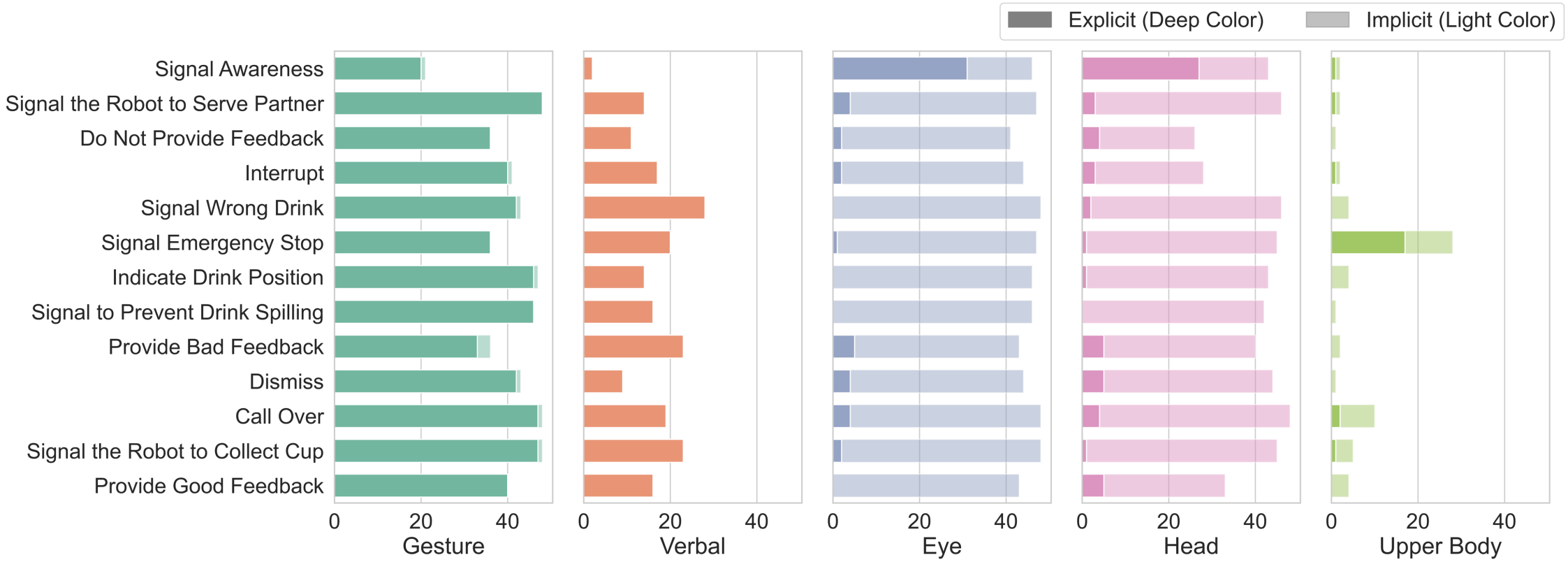

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Perception on Robots

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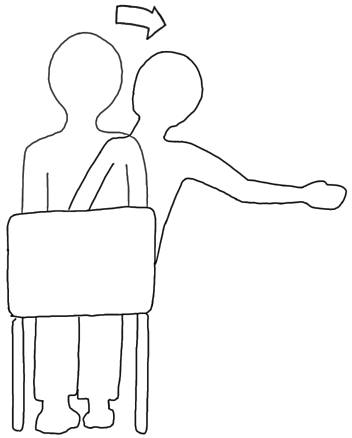

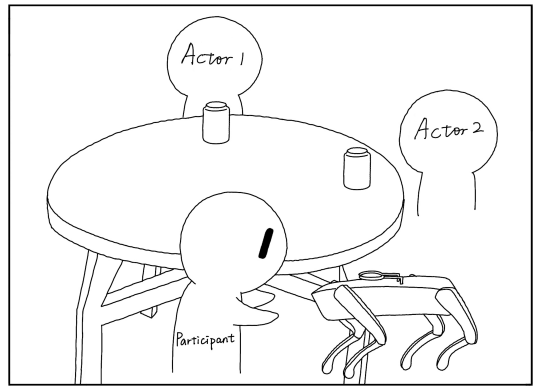

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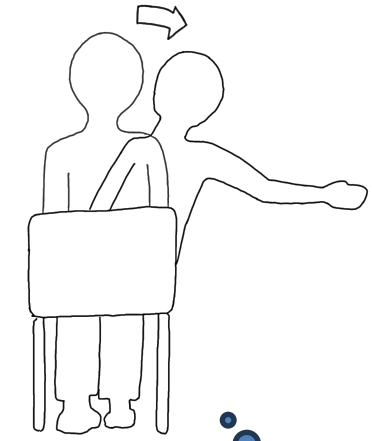
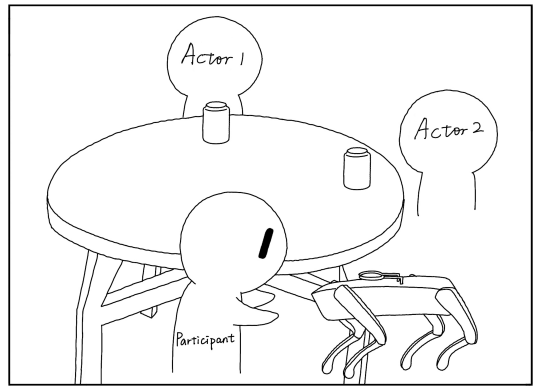
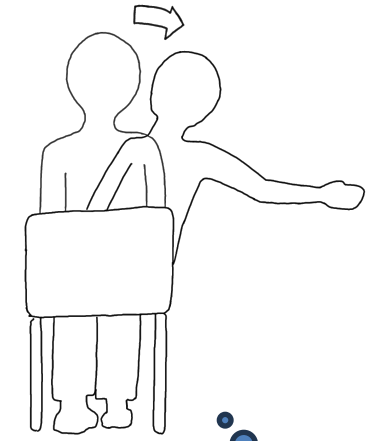


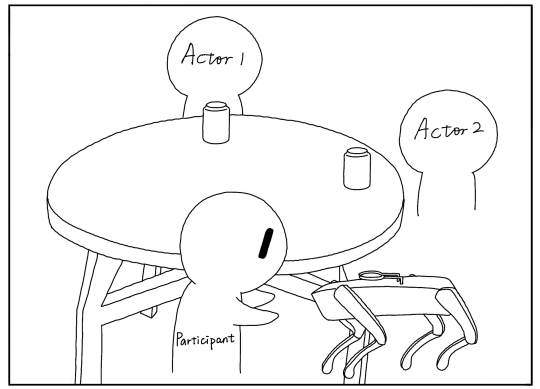


The camera and microphone are low

Perception on Robots

Alignment between Robot Capabilities and Users' Assumptions





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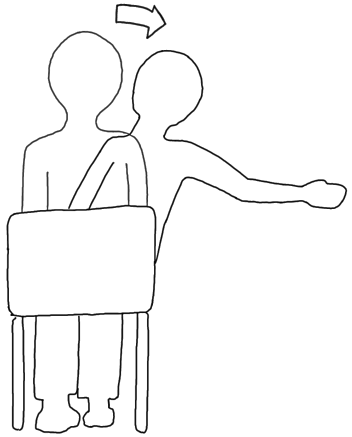

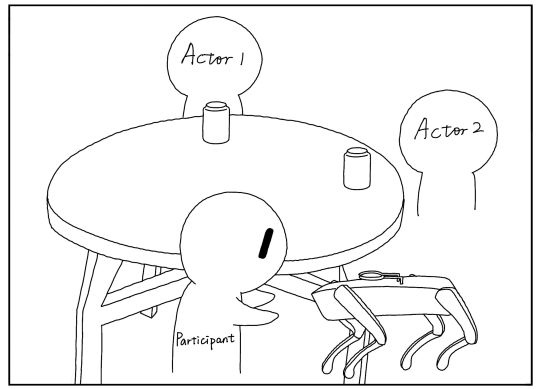

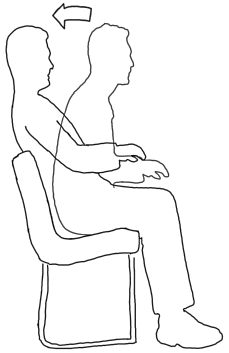

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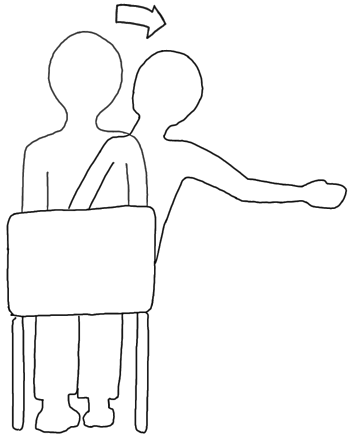

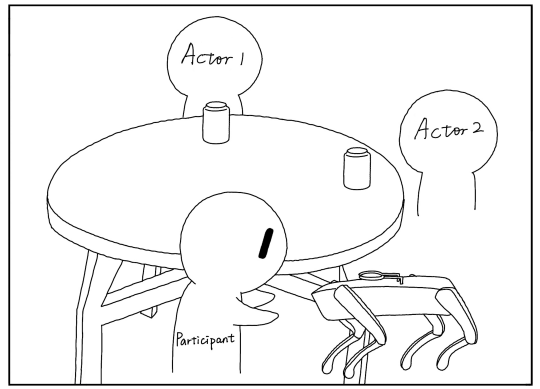

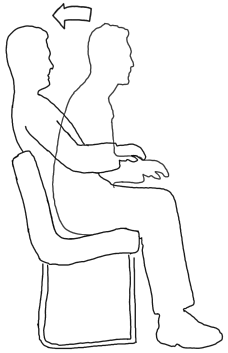

Proxemics Design

Perception on Robots

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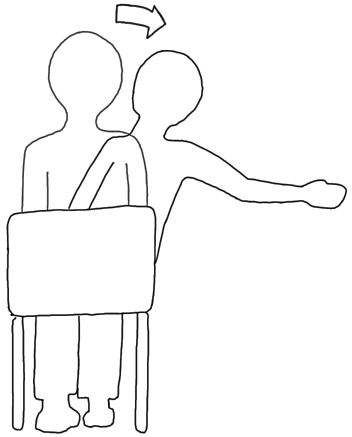

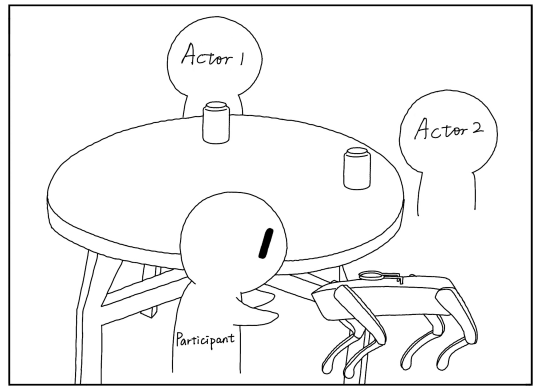

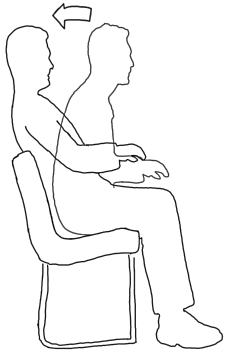

Proxemics Design

Alignment between **Robot Behaviors** and *Perceived Intelligence* of the **Robot Appearance**

Primary Task and Social Context

- Effects of ***ConversationalRole*** and Interview Results
  - More *verbal* and straightforward cues when *speaking*
  - Always choose socially appropriate cues
    - Avoid misunderstanding
    - Signal inconspicuously

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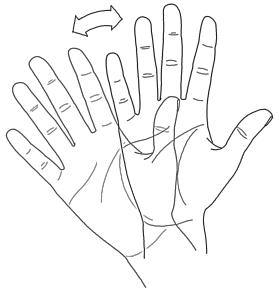

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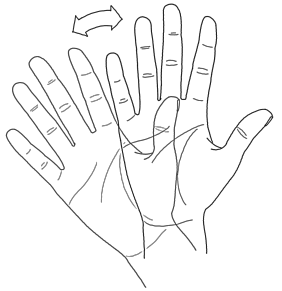

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Understanding Human Intentions Behaving Socially Appropriately

- According to the social context
- Given minimum set of social cues

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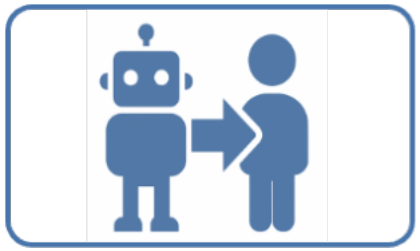
Design Implications



Robot Approaching Strategy

- Reduce unnecessary approaching
- Approach the one with less cognitive load
- Minimize interruption in necessary approaching

Human Social Cue Processing

Deduce interaction willingness
Learn common social cue semantics
Learn from implicit cues to disambiguate or understand the emphasis

Designed by Freepik

Robot Response

- Respond in a timely and socially appropriate manner
- Should be intuitive and easy to minimize interruptions
- Take proper strategies to repair failure

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Acknowledgment

Participants, actors and reviewers

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April 2025

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