Examining the legibility of humanoid robot arm movements in a pointing task

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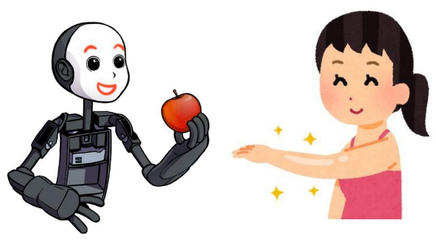
Introduction

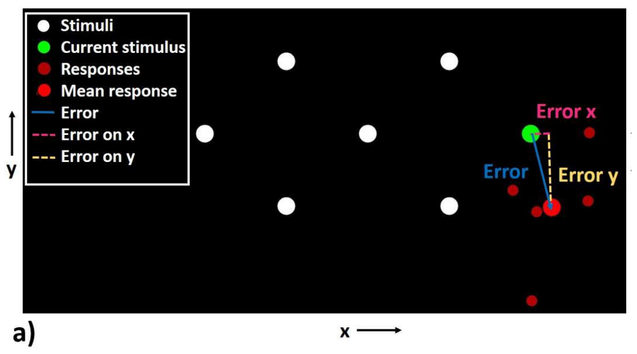
Smooth human robot interaction scenarios must involve robots that support human ability to interpret, predict, and feel safe around robotic actions 1 Hence the design of robotic motion must extend beyond efficiency in reaching a goal One of the critical features for effective, safe, and explainable collaboration is the legibility of the robot 2 comprehending the intent of the robot is fundamental for mutual understanding 3 4 To investigate the role of a legible behavior in a human robot interaction, it was essential to design a robotic behavior that could be repeatable and controllable 5 Thus, we created an interactive setting with the humanoid robot Nico to investigate humans' ability to predict the intentions of a robotic arm movement and/or its social cues (6 The motor behavior of the humanoid robot NICO 7 was characterized with a new method to generate precise and controllable robotic arm trajectories 8 Combined with the pose of the robot head, these two modalities served as information sources that human participants exploited in their inference task The study aimed at verifying that multimodal integration could induce better predictions, accompanied by a delay in the response compared to estimations in gaze only modality.



Experiment Setup and Methods

Task

Our study investigated how humans interpret incomplete humanoid robot arm movements in a pointing task. We utilized the NICO robot, equipped with 22 degrees of freedom and a touchscreen interface, to perform reaching actions toward predefined targets. Its arm trajectories were precalculated via gradient descent and forward

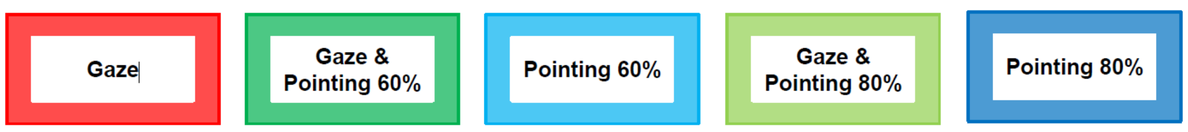


Robot's behavior

The NICO robot was programmed to point specific targets on a touchscreen, using two different modalities the gaze and the arm movement 60 or 80 trajectory)

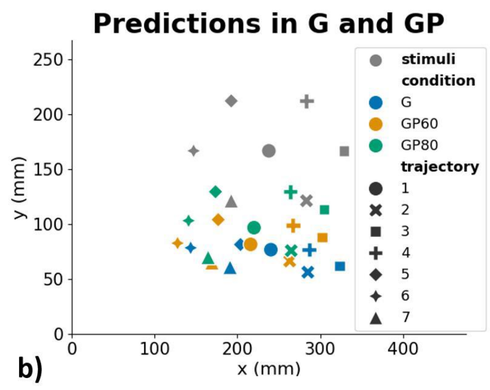
Its arm trajectories were computed via gradient descent and forward kinematics to ensure precision and repeatability

Experimental sessions

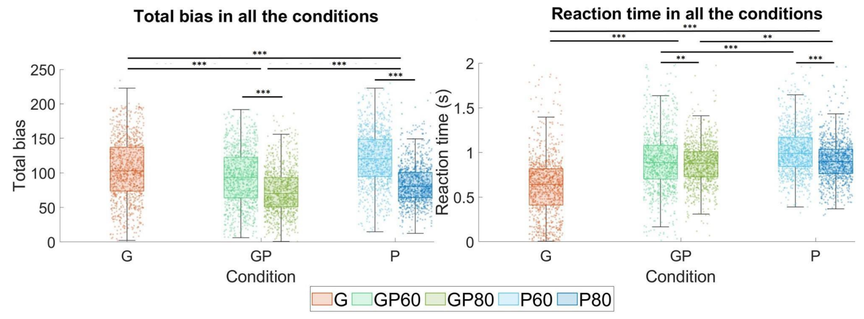


Results

1. Manipulation check: arm movements at 80% of the whole trajectory were substantially more legible than those stopped at 60% with prediction errors (bias) markedly reduced in presence of longer trajectory segments



2. Multimodal superiority hypothesis: combining gaze and pointing induced better predictions in unimodal conditions. Specifically, gaze pointing (GP) trials produced significantly lower bias than gaze only (G) or pointing only (P) trials, both at 60% and 80% trajectory.



3. Oculomotor primacy hypothesis: Reaction times were shortest in gaze only trials, demonstrating that gaze acted as a rapid and salient attentional cue. Although multimodal conditions yielded more accurate predictions, they required slightly longer processing times than gaze alone Nonetheless, combining gaze and pointing still produced faster responses than pointing alone, highlighting gaze's priming effect on processing.

Conclusions

- Providing additional motion information improves target inference
- The integration of multimodal cues allow humans to achieve more precise predictions of robot targets Additionally, results showed that gaze tended to mitigate lateral prediction errors particularly along the horizontal axis, reducing the tendency to misjudge endpoints
- Together, these results suggest that gaze provides quick but less precise guidance, while multimodal cues ensure higher accuracy This balance emphasizes the complementary

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Video

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Source codes