Biased Attention Near iCub's Hand After Collaborative HRI

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ABSTRACT

Earlier research has indicated that humans prioritize attention to the space close to their hands, commonly known as the "near-hand effect". This phenomenon also extends to a human partner's hand, but specifically following a shared physical joint action. Consequently, within human dyads, collaborative interaction results in a shared body representation that might impact fundamental attentional mechanisms. Our project investigates whether a similar effect can emerge from a human-robot interaction scenario. In previous work, we have shown that the mere presence of an anthropomorphic robot's hand is not enough to trigger the near-hand effect. Here, we designed an experiment to assess whether a collaborative human-robot interaction with the humanoid robot iCub could bias human attention toward the robot's hand. After the interaction, we replicated a classical psychological paradigm by adding a robotic condition to measure this attentional bias (i.e., the near-hand effect). Our findings indicate the existence of a near-hand effect triggered by the robot's hand, suggesting that HRI can replicate a shared body representation similar to that observed in human dyads, which may influence our basic attentional mechanisms.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**.

KEYWORDS

Human Attention, Near-Hand Effect, Collaborative Human-Robot Interaction, Posner Cueing Task

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1 INTRODUCTION

When individuals place their hands near a visual display, they undergo various visual and cognitive processing alterations. The presence of hands also impacts attentional processing, affecting visual search time [1] and biasing the allocation of spatial attention towards locations close to the hands, the so-called "near-hand effect" [15], [16]. This facilitation of attention near the hand suggests the potential engagement of bimodal neurons responsive to visual stimuli presented in the hand's proximity [8], [10]. This phenomenon enhances the visual processing of objects near the hand as potential candidates for future actions [5], [21].

However, there is still a gap in understanding whether the visual system similarly prioritizes information near the hands of another person. The hands of others hold special social significance, often used to direct attention through gestures like pointing, creating a shared focal point of attention [3]. It was proved that this attentional shift also appears towards a human partner's hand after a joint task [19]. These findings suggest that engaging in collaborative interactions with a human partner might impact the formation of a shared body representation that biases attention by directing cognitive focus toward the partner's hand as though it were ours.

One of the main objectives of the human-robot interaction community is to develop and employ robots capable of interacting and collaborating efficiently and naturally with human beings. To this aim, it is essential to explore the perceptual, motor, and attentional mechanisms that could support (or hinder) mutual understanding between the involved parties [17]. Our project aims to investigate the circumstances under which attentional biases, such as the near-hand effect, might also occur in human-robot interaction scenarios. In previous research, we have demonstrated that the mere presence of an anthropomorphic robot hand is not enough to trigger the near-hand effect [18]. Consequently, we addressed the following research question: "Can a collaborative interaction with the humanoid robot iCub bias human attention near the robot's hand?"

We replicated a human-human collaborative task in an HRI setting [19]. After that, we used a well-known psychology paradigm [14] to measure the near-hand effect, exploiting the iCub robot [9] as a controllable stimulus. From a technical perspective, iCub is an optimal choice since its hands have a structure and size similar to human ones and guarantee movements similar to ours. Moreover, it can act as a social agent and generate bio-inspired movements and actions [7], supporting compliance in physical interaction.

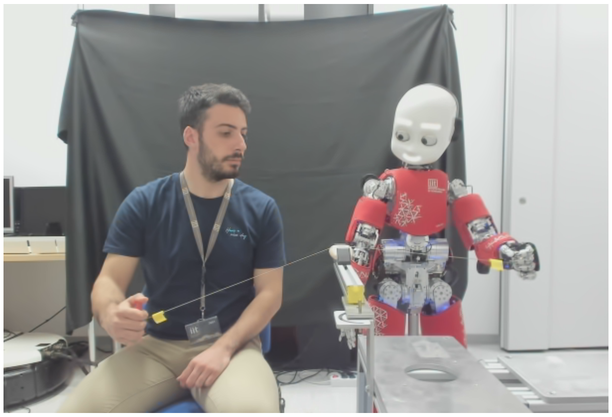

Figure 1: Collaborative HRI. The participant and the iCub hold one wire handle each and have to coordinate to cut a soap bar by exchanging forces through the wire.

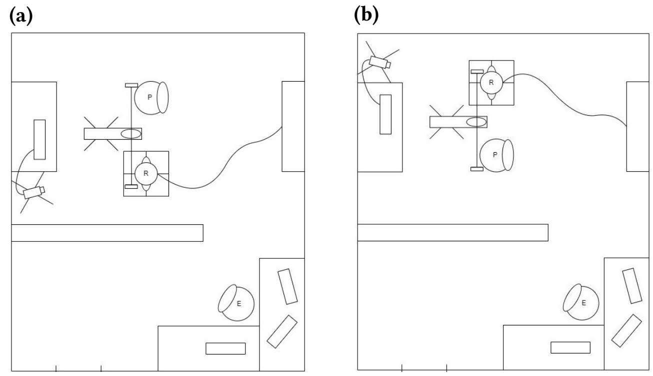

Figure 2: Collaborative HRI setup. (a) The participant (P) keeps the handle in the right hand, whereas the robot (R) uses its left hand; (b) the setup configuration is mirrored.

2 DESIGN AND METHODS

Thirty right-handed people participated in the study (17 females, 13 males; mean age = 28.87 y.o.; std = 9.38 y.o.). All participants had normal or corrected-to-normal vision and were naive to the purpose of the study. The Regional Ethical Committee approved the experimental protocol, and all participants provided written informed consent before starting the experiment.

2.1 Collaborative HRI

Previous studies proved that collaborative interaction results in a joint body schema that might impact basic attentional mechanisms. To investigate whether a humanoid robot might trigger similar attentional biases, we replicated a human-human collaborative task in an HRI scenario with the humanoid robot iCub (see Fig. 1). The experiment involves a human-robot dyad in physical joint action, consisting of a sawing task. The parties have to cooperate to cut a soap bar using a steel wire. Each party holds one wire handle and needs to coordinate with the partner to achieve a common goal: maximizing the cut.

2.1.1 Robot Control. The robot's movements during the interaction are controlled in position. We designed a loop trajectory between two desired points. Moreover, while moving inside this loop, the robot is compliant, meaning its positions can be perturbed by the participant pulling at each point of its trajectory. Compliance choice has two reasons: on the one hand, it guarantees a safer interaction to prevent the robot from breaking; on the other hand, it helps make the robot's behavior adaptive, leading to more personalized interactions.

2.1.2 Apparatus & Procedure. The experimental setup includes the humanoid robot iCub, a steel wire with two handles, a new soap for each participant, and a rod to support the soap halfway between the participant and the robot during the exercise. Half of the participants did the task with their right hand while the robot was using its left hand (Fig. 2a), whereas the other half did the opposite (Fig. 2b) to avoid possible side effect due to the use of the dominant hand. The experimental session lasted four minutes, during which participants could not interact with the experimenter but just had to focus on the task in collaboration with the robot.

2.2 Posner Cueing Task

After the collaborative interaction, participants performed an attentive task that we used to investigate whether the HRI impacted human attention. More precisely, we designed an experiment to evaluate whether the near-hand effect generalizes to a robotic anthropomorphic hand presented by the iCub robot. The participants performed a well-known psychological paradigm called the "Posner cueing task" while sitting beside the iCub. The Posner cueing task is a classical paradigm used to study visual attention [14].

2.2.1 Visual Stimuli. Two empty squares (3.4°) appear on both sides (7.4°) of a central fixation cross (3.4°). After a random time interval between 1500-3000 ms, one square is cued by increasing the thickness of its borders for 200 ms, and then a target appears (black dot; 2.2°). The user has to press a button on a keyboard as soon as the target appears. If the target appears in the cued square, this is classified as a valid trial (Fig. 3a); if the target appears in the other square, this is classified as an invalid trial (Fig. 3b). Rarely, the square remains cued for 2000 ms without the target appearing; these are classified as catch trials (Fig. 3c) and are used to check if the participant is still focused on the task. We used 70% valid trials, 20% invalid trials, and 10% catch trials in random order.

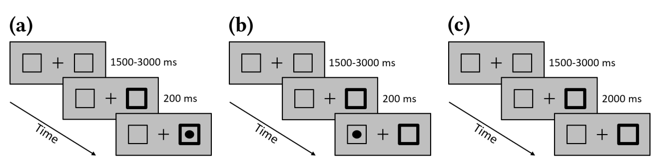

Figure 3: Posner cueing task. Trials classification: (a) valid trial if the target appears in the cued square; (b) invalid trial if the target appears in the not cued square; (c) catch trial if the target does not appear.

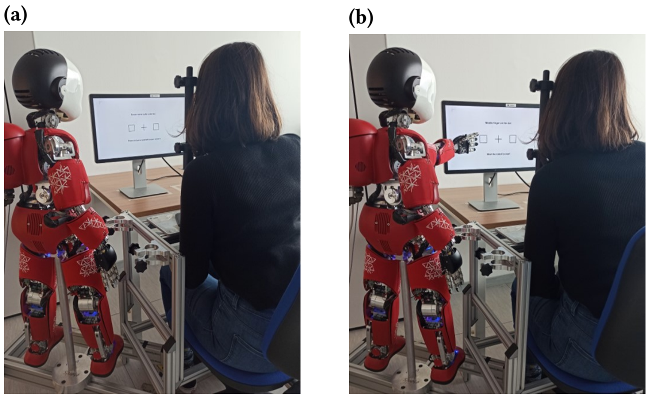

Figure 4: Posner cueing task setup. Conditions: (a) no-hand near the screen; (b) robot's hand near the screen.

2.2.2 Apparatus & Procedure. The experiment was programmed in MATLAB using the PsychToolbox extension. Visual stimuli were drawn in black against a light grey background on a monitor with a 1024 × 768 pixels display resolution. We used a chin rest to maintain the participant at a fixed distance from the screen (i.e., 50 cm). Participants responded by pressing the space bar on a keyboard, regardless of the side of the target's appearance. Half of the participants did the exercise with their right hand, and the others used their left hand, employing the same hand involved in the collaborative interaction. The Posner task was performed under two possible conditions, namely, with no hand in the participant's field of view (Fig. 4a) or with the robot's hand near one of the target locations in the participant's field of view (Fig. 4b). The setup was the same for both conditions. Each experimental session included four blocks of 60 trials, two with no hand near the screen and two with the robot's hand near the screen. The block order was randomized.

3 RESULTS

We considered the participants' reaction times for target detection as the dependent measure of our interest. The reaction times (RTs) of the responses were filtered between two thresholds: RTs > 200 ms, following the average physiological threshold for RTs in human beings [11], and RTs < 1000 ms, replicating the research by Sun & Thomas [19]. Consequently, 6.5% of the trials were discarded because the RTs fell outside the 200–1000 ms window. Moreover, the average error rate of the participants in catch trials was 8.3%, and none of them exceeded 20% of errors.

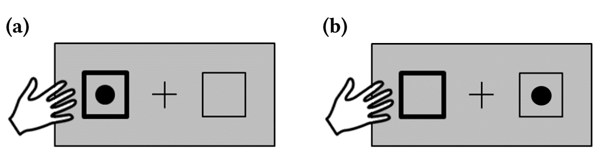

Figure 5: Hand congruency during the Posner cueing task. Hand position: (a) hand congruent if the target appears on the same side of the hand near the screen; (b) hand incongruent if the target appears on the opposite side.

We used paired sample t-tests for the statistical analysis to compare the participants' average RTs between the two experimental conditions. The first test was done to verify the Posner cueing task validity. We found a significant effect of cue validity, proving that participants detected the visual targets faster in valid than invalid trials. Cue validity is verified for both the experimental conditions with these results: $t\ (30) = 8.98$, $p < 0.001$, Cohen's $d = 1.59$ in no-hand and $t\ (30) = 13.05$, $p < 0.001$, Cohen's $d = 2.30$ in robotic condition. Anyway, cue validity did not affect the near-hand effect.

Regarding the second analysis, we examined hand congruency, which prescribes whether the robot's hand near the screen is positioned on the same side as the appearing target or on the opposite side. In particular, we refer to "hand congruent" trials (Fig. 5a) when the hand and target are on the same side, whereas in "hand incongruent" trials (Fig. 5b) the hand and target are on the opposite side.

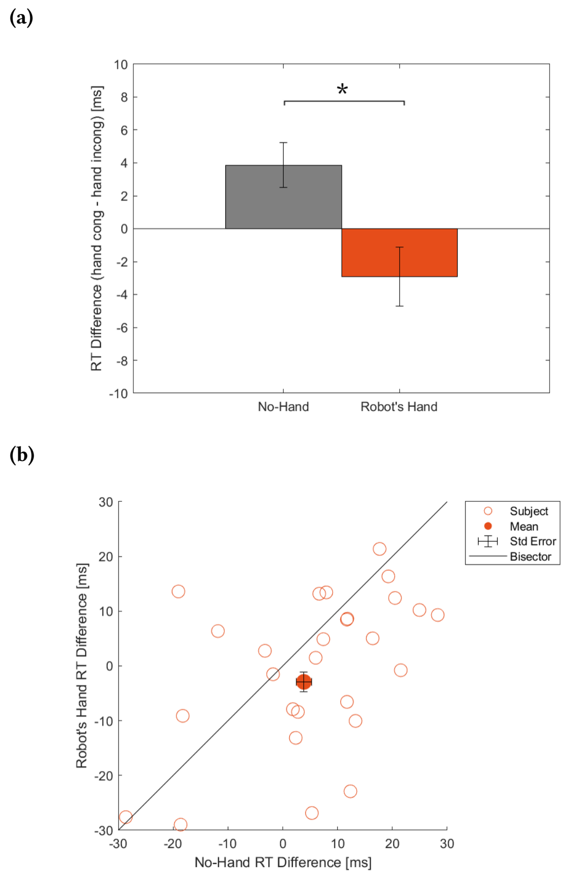

Figure 6: (a) The grey and red bars display the difference between the average RTs in hand congruent (Fig. 5a) and hand incongruent (Fig. 5b) trials. The error bars represent the between-subjects standard error of the means. A significant difference exists between the no-hand (grey bar) and robot's hand (red bar) conditions, meaning the robot's hand speeds up target detection. (b) The scatter plot shows the effect is quite consistent among subjects. Most dots, each representing one subject, lie under the bisector.

The two bars in Fig. 6a show the difference between the average reaction times in hand congruent and hand incongruent trials, referring to the no-hand (grey bar) and the robot's hand (red bar) conditions. The error bars represent the standard error.

Results found the aimed near-hand effect when performing the attentive task with the robot's hand near the screen, leading to significantly shorter reaction times when detecting the target in hand congruent trials: $t(30) = 2.25$, $p = 0.032$, Cohen's $d = 0.40$. The scatter plot of Figure 6b displays the results are quite consistent across participants. Indeed, most of the dots, each representing one subject, lie under the bisector, meaning most of the participants' average RTs are shorter in the robot's hand condition than in the no-hand condition, as confirmed by the mean value.

4 DISCUSSION AND FUTURE WORK

The principal objective of this project is to evaluate whether engaging in physical collaborative interaction with the humanoid robot iCub might influence basic attentional and perceptual mechanisms in humans, a phenomenon previously identified in human-human interaction scenarios.

Our experiment demonstrated that a collaborative HRI could bias human attention near the robot's hand, following the "near-hand effect." The interaction consisted of a shared physical joint task inspired by existing human-human research [19]. After the collaborative interaction, we replicated a psychological paradigm, i.e., the Posner cueing task [14], to measure the shifting in human attention. We verified our hypotheses by replicating the human-human study. Indeed, we found the near-hand effect of the robot's hand after the physical HRI, meaning the presence of an anthropomorphic robot's hand in the human partner's field of view impacted where human attention was focused during the execution of the Posner, increasing human velocity in detecting visual stimuli.

These findings expand the results of research conducted with fake human-like hands [4], other persons' hands [6], and anthropomorphic robot's hands [18]. When participants have a reason to incorporate a representation of another's hands into their own body schema, their visual systems show altered processing near these hands. Indeed, we demonstrated that an anthropomorphic robot's hand, as a friend's human hand, is not per se sufficient to shift human attention toward itself but can trigger the near-hand effect only after the parties share a collaborative interaction. The implications of these findings are noteworthy, suggesting a shared cognitive response to anthropomorphic features in both human and robotic entities. This insight is relevant for our comprehension of human-robot interaction dynamics and for the design and implementation of robots in contexts where influencing human attention is a critical aspect of the interaction.

The limitations of our current work and potential future work are connected. Implementing a predefined behavior for our robot allowed for precise control and quantitative assessment of interaction dynamics, offering insight into features of joint action that contribute to the "joint" near-hand effect observed in human collaboration. Nevertheless, up to now, we have no clues about which aspects of the interaction mainly contributed to triggering the near-hand effect (e.g., the force exchange, the synchronization dynamic, the robot's social behavior, etc.). Hence, we would like to replicate our study by isolating the different components concurring in the physical HRI to understand better which ones mainly affected our previous findings. For instance, manipulating the robot's behavior enables an examination of the social component's role, impacting levels of social intelligence and influencing fundamental perceptual mechanisms, including human space perception [13].

Finally, another crucial aspect concerns adaptation, a fundamental skill observed in natural (biological) cognitive agents, evident both in their behavior and physiological responses. The latter remains quite an open challenge in the HRI field [2], [20]. Adaptability is essential for implementing artificial cognitive agents, enabling them to integrate into new environments, navigate changes in their surroundings, and establish the groundwork for a sophisticated, human-like interaction with other agents [22]. Leveraging the adaptability of the iCub in our research could prove valuable to go deeper into this topic. For instance, by replicating our experiment and programming the robot to adjust its behavior based on the partner it is interacting with, we can naturally allocate leader-follower roles, replicating the dynamics observed in human dyads [12]. This could potentially enhance the quality of the human-robot interaction and the emergence of the "joint" near-hand effect, impacting human attentional mechanisms.

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