# Coordinating With a Robot Affects Neural Processing Related to Action Monitoring

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Robots start to play a role in our social landscape, and they are progressively becoming responsive, both physically and socially. It begs the question of how humans react to and interact with robots in a coordinated manner and what the neural underpinnings of such behavior are. This exploratory study aims to understand the differences in human-human and human-robot interactions at a behavioral level and from a neurophysiological perspective. For this purpose, we adapted a collaborative dynamical paradigm from the literature. We asked twelve participants to hold two corners of a tablet while collaboratively guiding a ball around a circular track with either another participant or a robot (Yumi, ABB, Sweden). In irregular intervals, the ball was perturbed outward creating an artificial error in the behavior, which required corrective measures to return to the circular track. Concurrently, we recorded electroencephalography (EEG). During preprocessing, the EEG data was downsampled to 512Hz and filtered from 0.1Hz to 120Hz. Following this, we manually removed channels that showed strong drift behavior or excessive noise. We manually inspected the continuous data stream and rejected the portions, which exhibited strong muscle artifacts or jumps. Furthermore, we used independent component analysis to remove eye and muscle movements. Finally, using spherical interpolation, we interpolated the missing channels based on activity recorded from the neighboring channels. In the behavioral data, we found an increased velocity and positional error of the ball from the track in the human-human condition vs. the human-robot condition. For the EEG data, we computed event-related potentials with respect to the induced error. To explore the temporal and spatial differences of error processing in the two conditions, we used time-regression with overlap-control and corrected for multiple-comparisons using Threshold-Free-Cluster Enhancement. We found a significant difference between human and robot partners driven by significant clusters at fronto-central electrodes. The amplitudes were stronger with a robot partner, suggesting a difference in neural processing which might reflect action monitoring or an error related negativity. All in all, our exploratory study suggests that coordinating with robots affects action monitoring related processing. In the investigated paradigm, human participants treat errors during human-robot interaction differently from those made during interactions with other humans.

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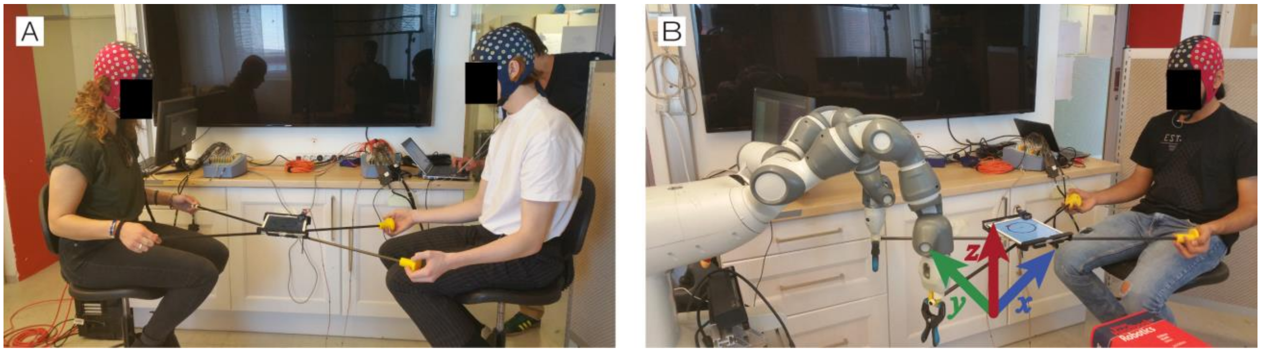


*Figure 1: Experimental Setup. Participants performed the experiment with another participant (A) or a robotic partner (B). In each condition, they played a tablet game by balancing a virtual ball on a circular track while moving in the counter-clockwise direction.*

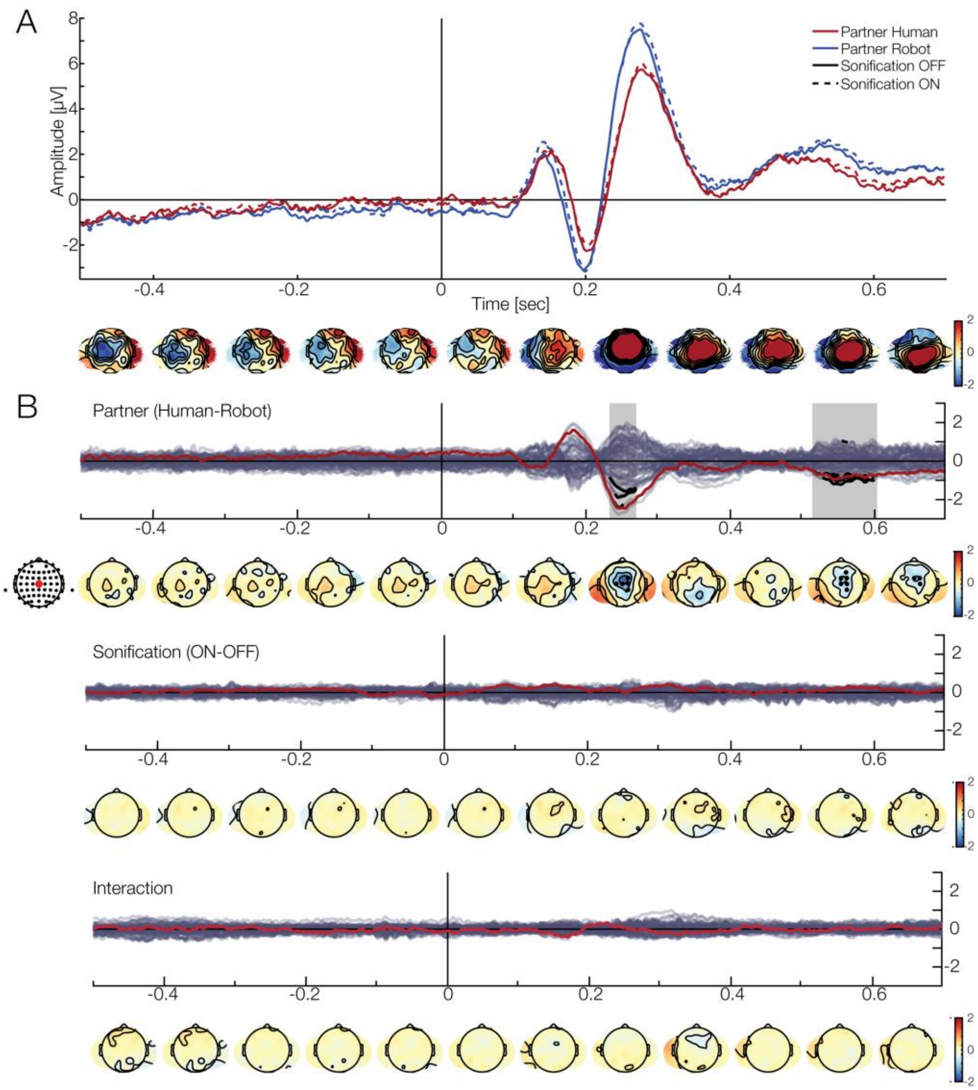


*Figure 2: EEG results. (A) ERP at electrode Cz. The red lines show the activation when interacting with a human partner, while the blue lines indicate a robotic partner. The solid lines are the ERP when sonification was off, while the dashed lines represent sonification "on". Below are the topographies for the grand average (mean over all conditions). (B) Clustering results for the different factors. Top: Effect of partner. The analysis finds two clusters in the central area (red line and dot represent electrode Cz). One is likely due to a difference at around 230ms to 270ms, while the second one is present later (around 510ms to 600ms). These results indicate that the ERP will have a smaller amplitude when interacting with a human partner. Middle: Effect of sonification. No cluster was found here. Bottom: Interaction. No cluster was found here*