Investigating event-related potentials during movement preparation and outcome error processing to compare between motor adaptation and de novo learning

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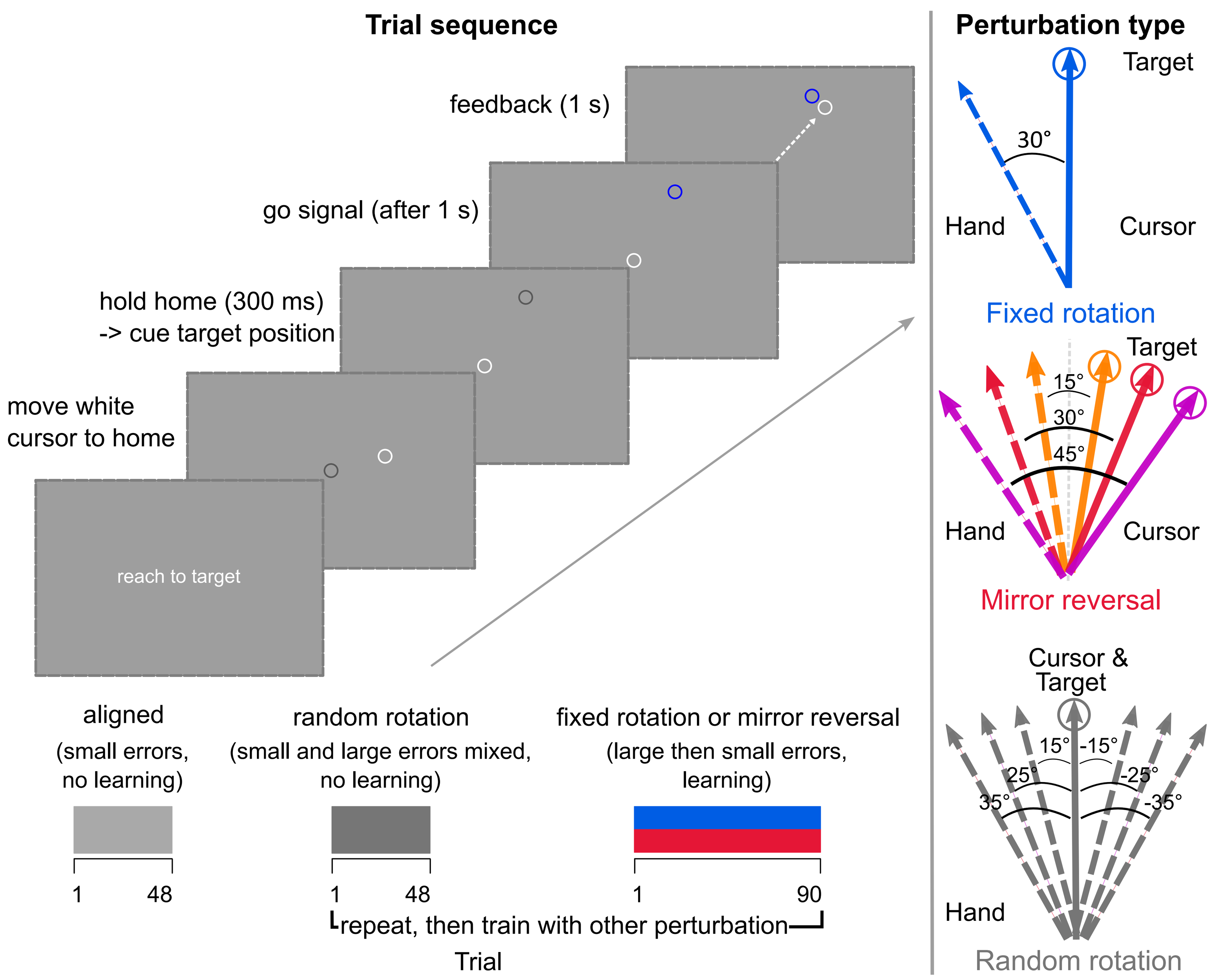
Using electroencephalography to investigate motor learning

Movement error processing contributes to motor learning, either when we are adapting well-known movements or acquiring new motor skills (de novo learning). Previous research has distinguished the behavioral mechanisms of these two motor learning types, but we understand less about their underlying neural mechanisms. Here, we investigated event-related potentials (ERPs) associated with movement preparation and error feedback processing of reaching movements.

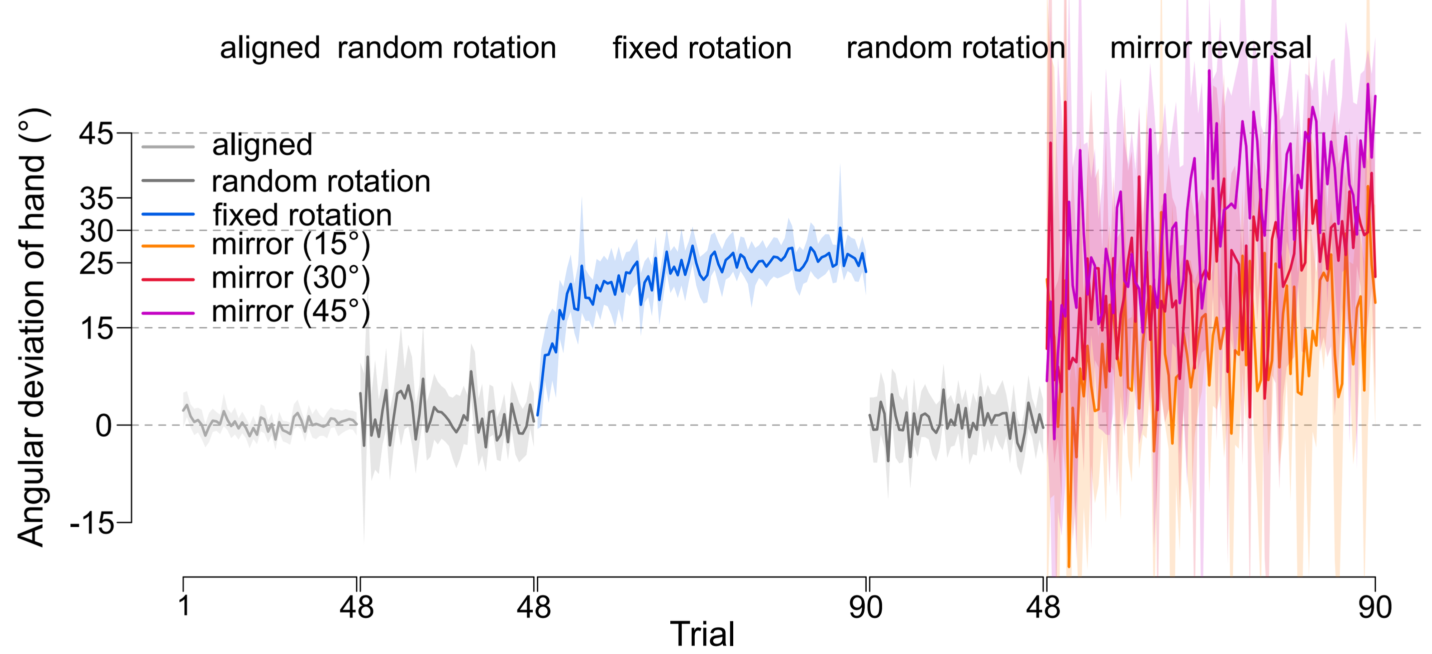
Visuomotor rotation versus mirror reversal



Participants (N = 32) reached towards different target locations using a stylus on a tablet, while we recorded EEG from 64 channels. We distinguished motor adaptation from de novo learning by having participants train with two perturbation types in counterbalanced order: a 30° visuomotor rotation to investigate adaptation and a reversal of cursor feedback in the opposite direction of a mirror axis for de novo learning. Prior to training in each perturbation type, participants encountered a random rotation as a control condition.

Learning occurs for rotation and mirror perturbations only

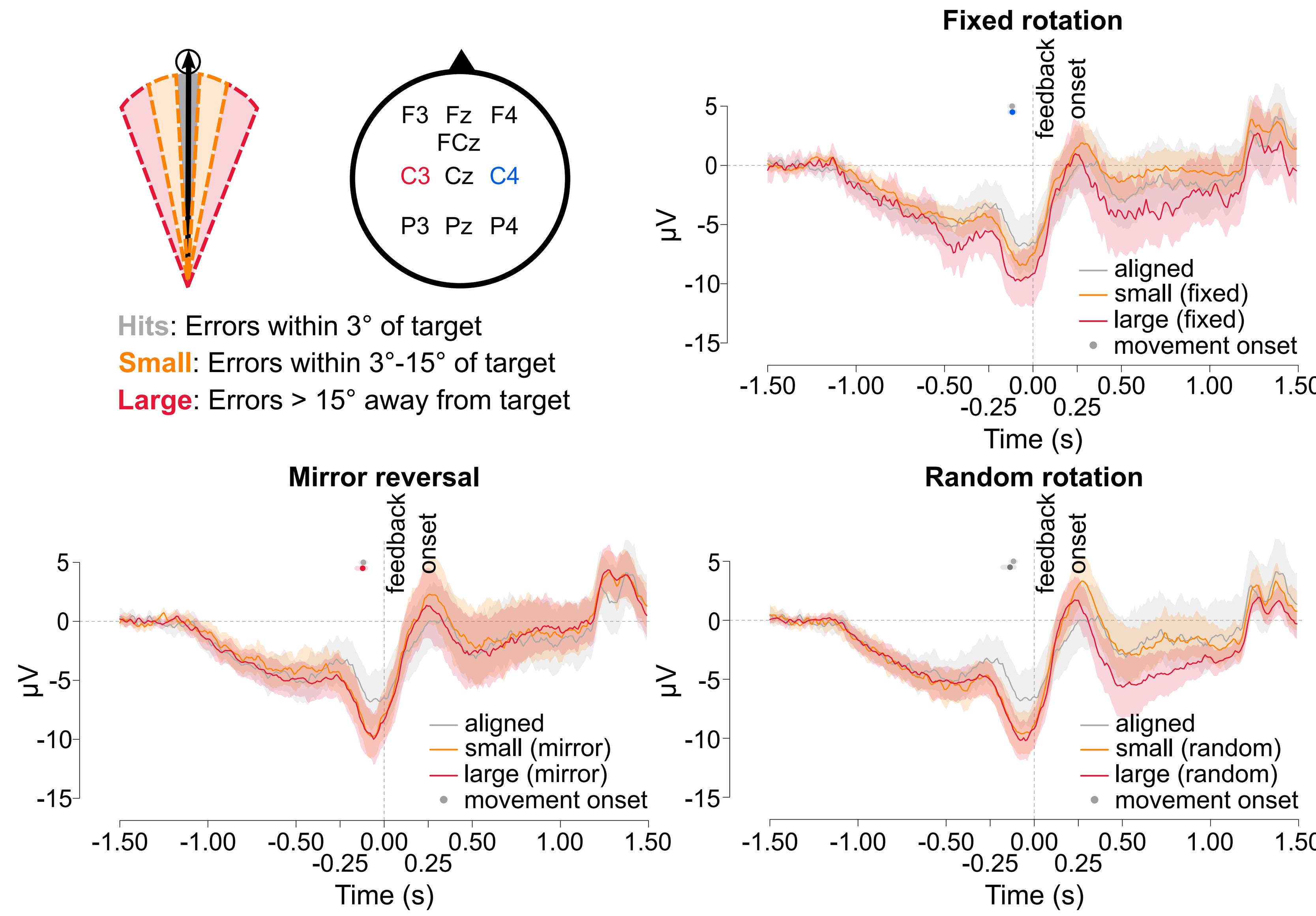
Participants learned to compensate for both the rotation and mirror reversal, but did not learn when the perturbation was unpredictable. Learning in the mirror reversal had more variability than in the rotation.



ERPs in response to movement error

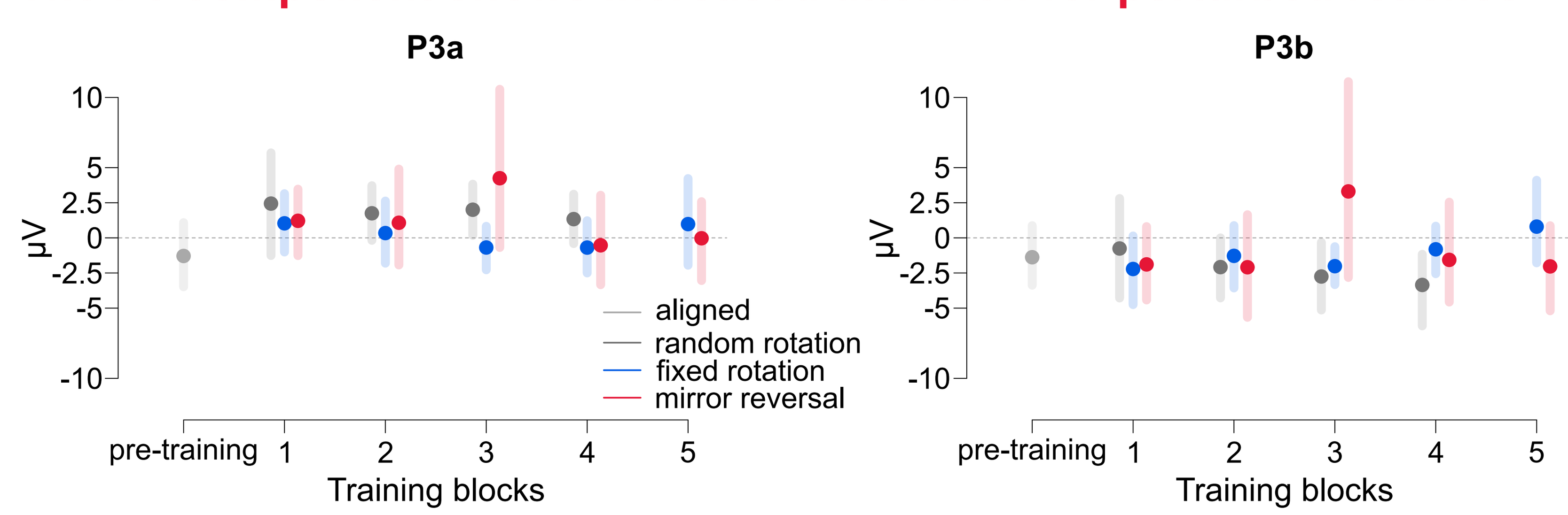
ERP components in relation to movement errors are the Error-Related Negativity (ERN) and Feedback-Related Negativity (FRN). While the ERN is typically measured during the movement and may reflect a prediction of movement outcome, the FRN peaks after feedback onset indicating the success of the movement. For each perturbation type, we split the reach data according to error magnitude. We time-locked the EEG signals to feedback onset and compared the ERPs across the conditions. The ERPs were calculated from an average of 10 fronto-central and parietal electrodes.

ERP prior to feedback onset distinguishes aligned from perturbed trials, but not across perturbation types



We observed a negative ERP component peaking before the feedback onset, which was less negative for aligned trials compared to the peaks in the perturbed conditions. ERP peak amplitudes did not change across perturbation conditions, but there seems to be a difference between small and large errors for the fixed rotation. There also seems to be a difference between small and large error conditions around 0.5 s after feedback onset in the fixed and random rotation conditions.

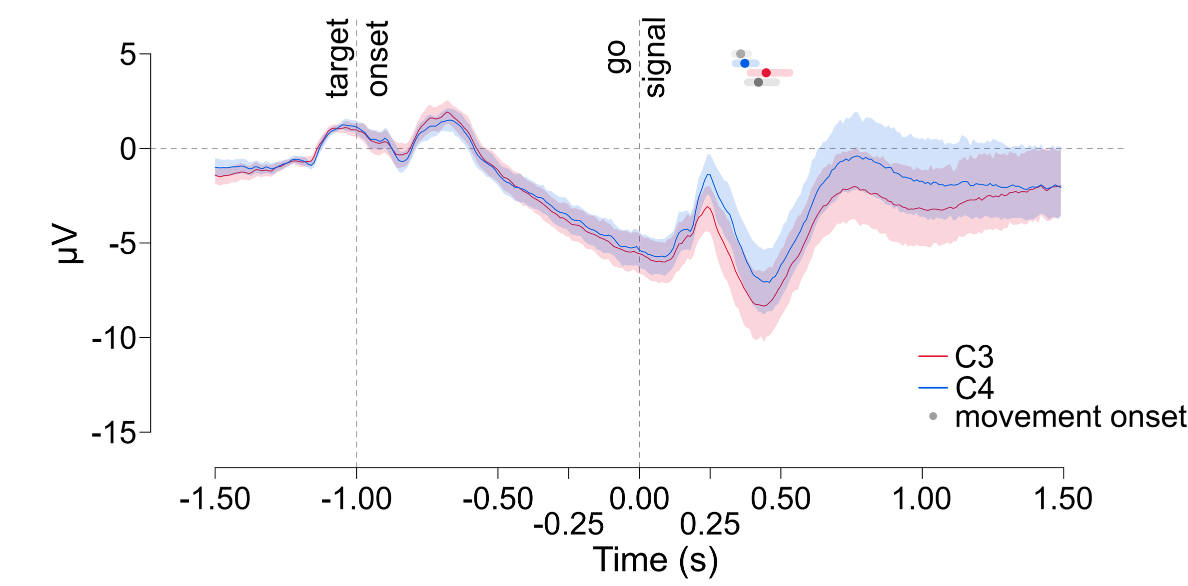
The P3 component shows increased attention for perturbed reaches



P3 is a positive-going component that has two subcomponents: P3a (~150 to 280 ms post-feedback) and P3b (~280 to 500 ms post-feedback). Increased P3a amplitude reflects increased focal attention, and increased P3b amplitude reflects context updating given the stimulus information. We calculated ERPs for the Fz, FCz, Cz, and Pz electrodes and show peak amplitudes of both subcomponents across blocks of training trials. We observed larger P3a amplitudes in perturbed compared to aligned reaches during the first few training blocks, suggesting more attention allocation during perturbed reaches.

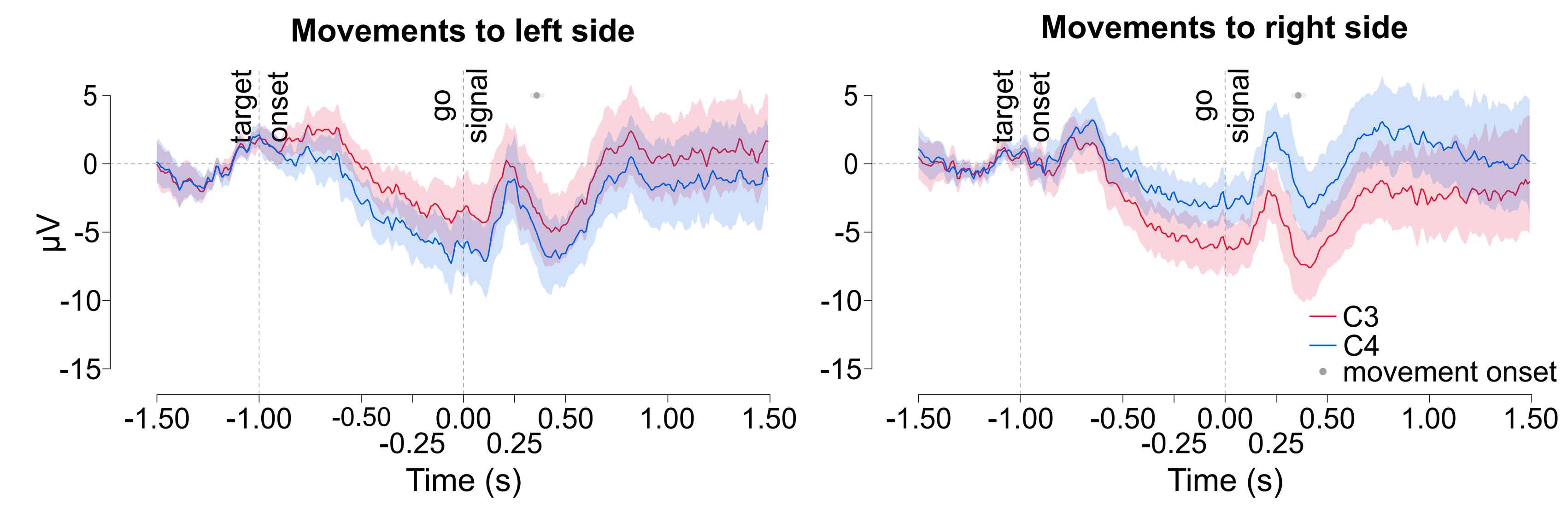
ERP during movement preparation

The Readiness Potential (RP) is associated with neural processing during movement preparation. We time-locked the EEG signals to the go signal onset and calculated ERPs for the C3 and C4 electrodes. We observed the RP prior to the go signal onset.



The readiness potential depends on prepared movement direction

We further analyzed the slow-drift wave prior to the go signal, and compared the C3 and C4 signals when participants either moved to the left or right side of the workspace.



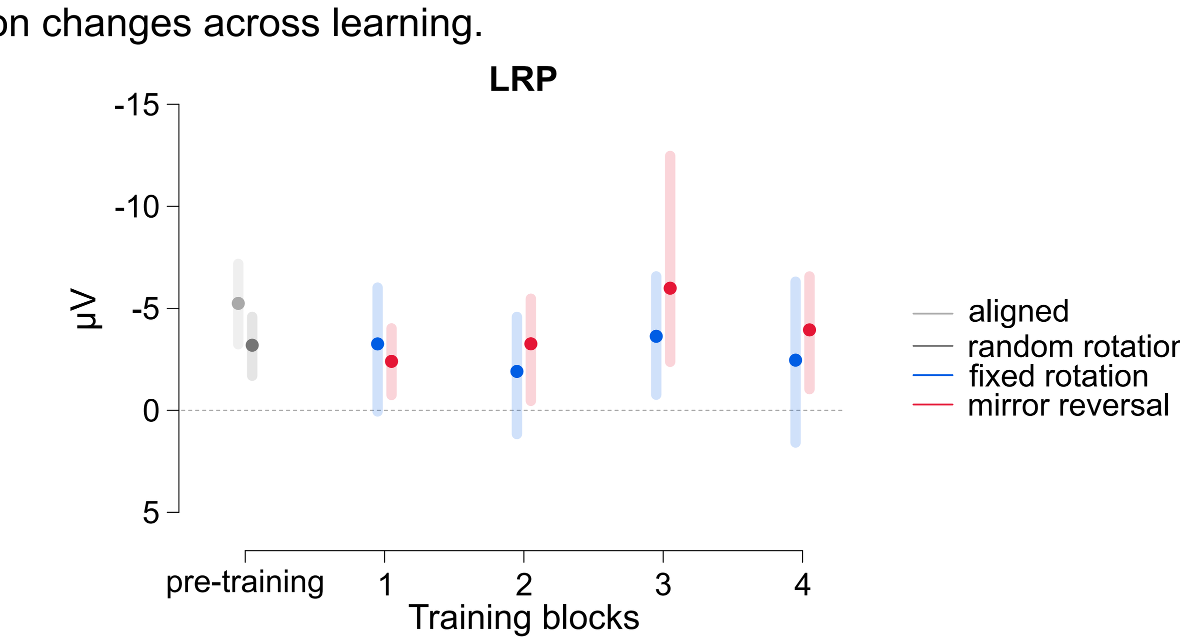
For both aligned and perturbed conditions, we observed that C4 showed more negativity than C3 for leftward movements, while this relationship was flipped for rightward movements.

Movement preparation ERPs in rotation and mirror tasks do not differ

Given that the readiness potential takes into account the prepared movement direction, we calculated a Lateralized Readiness Potential (LRP):

$$LRP = (\text{right } C3 - \text{right } C4) - (\text{left } C3 - \text{left } C4)$$

We used the LRP as a measure of preparatory activity in the upcoming movement. That is, more negative LRPs would indicate more preparatory activity. We then calculated LRPs across different blocks of training trials in each of the perturbation conditions, to quantify movement preparation changes across learning.



The LRPs were less pronounced for the perturbed conditions than in aligned reaches, but overall we found no LRP differences between rotation and mirror perturbations.

ERPs that reflect movement preparation and error processing do not seem to distinguish between motor adaptation and de novo learning

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