Neural markers for movement preparation and error processing during motor adaptation and de novo learning

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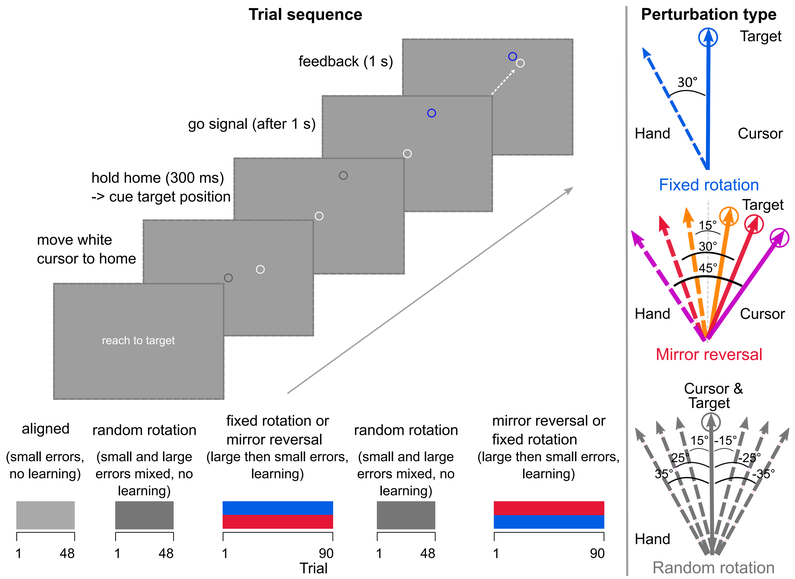
Electroencephalography and motor learning

As people encounter movement errors due to changes with their own body or the environment, they process these errors to correct for ensuing movements. This error processing contributes to motor learning, either when we are adapting well-known movements or acquiring new motor skills (de novo learning). While numerous behavioral studies have compared these two motor learning types, we understand less about their underlying neural mechanisms. Here, we investigated event-related potentials (ERPs) associated with movement preparation and error feedback in two reaching tasks.

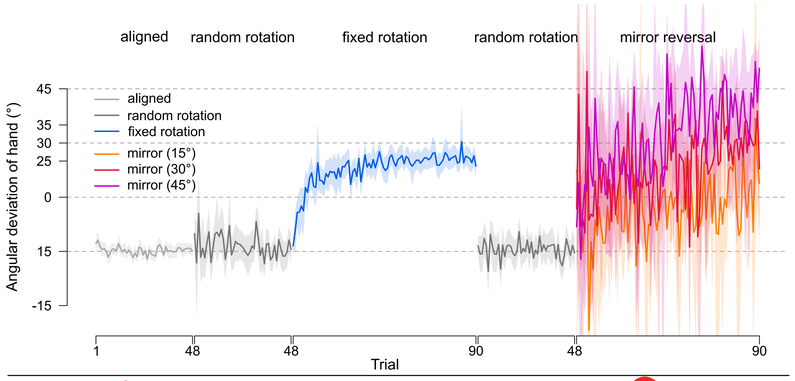
Visuomotor rotation versus mirror reversal

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 and a reversal of cursor feedback in the opposite direction of a mirror axis. Prior to training in each perturbation type, participants encountered a random rotation as a control condition.



No learning occurs for random perturbations

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



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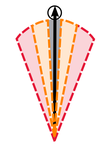
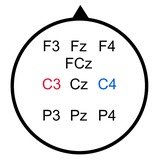
ERP in response to movement error

For each perturbation type, we split the reach data according to error magnitude.



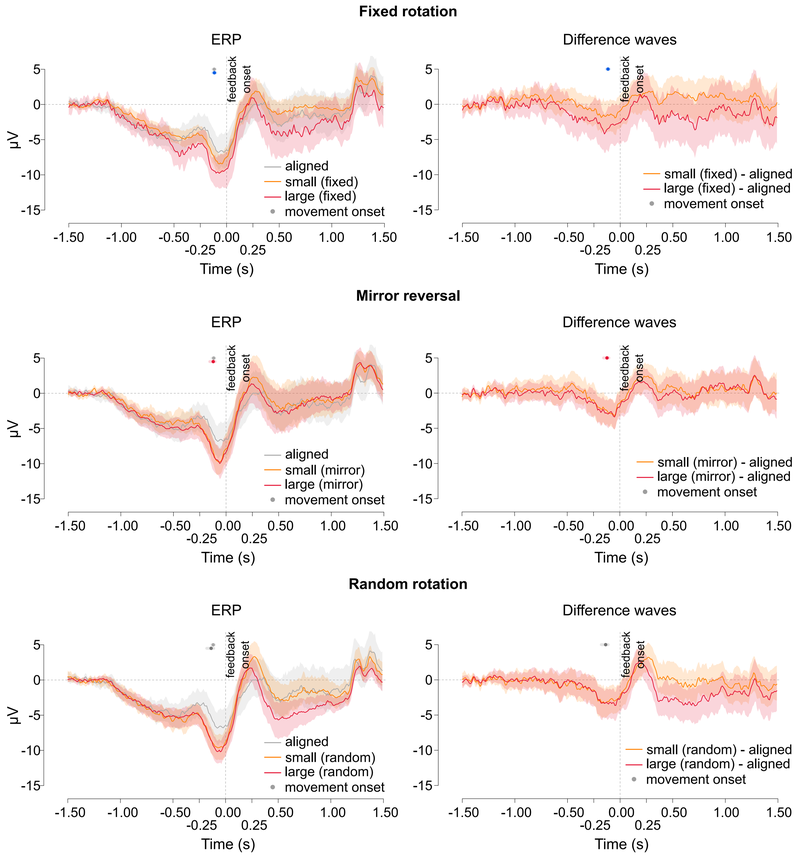
Hits: Errors within 3° of target
Small: Errors within 3°-15° of target
Large: Errors > 15° away from target



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. 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.

The ERP distinguishes aligned from perturbed trials

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.

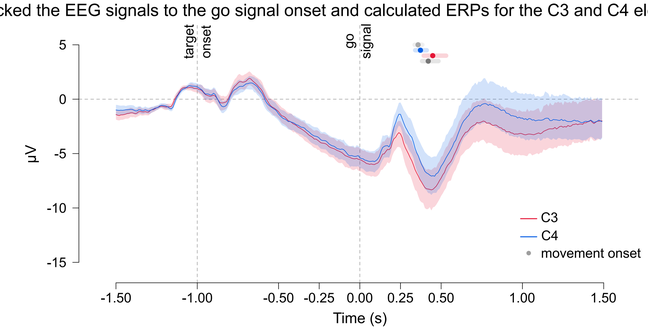


The ERP does not scale to perturbation type or error magnitude

ERP peak amplitudes of difference waves did not change across perturbation conditions. However, 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.

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. C3 showed more negativity than C4 just before movement onset, which is expected since participants performed right-handed movements. However, this C3 and C4 difference did not change between the aligned and perturbed conditions.

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.

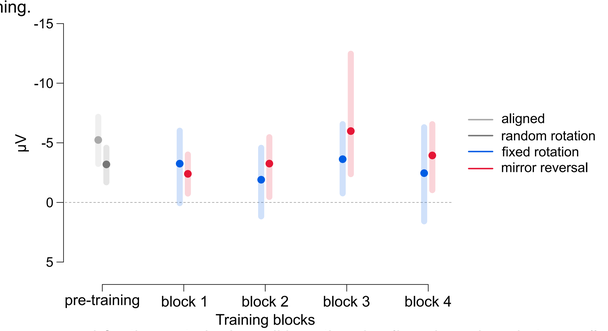
For the aligned condition, we observed that C4 showed more negativity than C3 for leftward movements, while this relationship was flipped for rightward movements.

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 = (right C3 - right C4) - (left C3 - 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 trials during training 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