Brain biomarkers for assessing practice of robotic arm reaching movements using a head-controlled interface

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Introduction

Research Question:
How are cognitive-motor processes modulated during the practice of a novel sensorimotor map used to control a robotic end-effector?

Previous Work:
- Upper-extremity cognitive-motor mechanisms practicing a new motor task are well documented in individuals without disabilities[1-2].
- Beta power has been associated with improved performance while learning related to memory formation[3-4] and attentional refinement[4-5].
- Applications of new sensorimotor maps are required while operating body parts with non-traditional functions [6-8].

Gap:
Beta power cerebral cortical dynamics could help identify practical and theoretical information underlying the neural engagement of resources in novel task practice.

Hypotheses:
1. Performance will improve over the practice session.
2. Low-beta and high-beta power will increase in planning and execution stages of task completion over the practice session.

Significance:
- Inform underlying cognitive-motor processes during the acquisition of a novel sensorimotor map.
- Provide bio-markers for practice monitoring during rehabilitation.
- Inform monitoring and (re-)training of individuals with disabilities using assistive technologies.

Methods & Materials

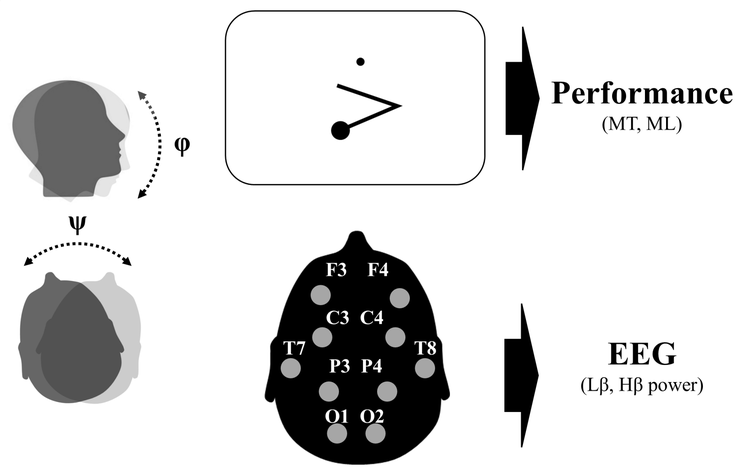


Figure 1. ***Experimental set-up.*** Performance of the end-effector (top right) controlled with a combination of pitch and yaw head motions (left) while recording brain activity via an EEG (bottom right).

Task:
Execute a reaching task by moving their head to control an end-effector to targets on the screen in front of them as straight and as quickly possible.

Phases:
1. Calibration phase for range of motion.
2. Brief familiarization phase.
3. 200 randomly appearing targets equidistant to the previous.
4. Complete transfer task.

Participants
18 right-handed individuals without disabilities or prior experience of using head-controlled systems (10 female, 8 male, 18-35 years) were recruited from UMCP.

Motor Performance
- ***Movement Time (MT):*** Movement onset to reaching the target.
- ***Movement Length (ML):*** Path travelled by end effector during movement.

EEG
- ***Low-beta*** (14-22Hz)
- ***High-beta*** (23-35 Hz)
- ***Planning*** (-1s to movement onset)
- ***Execution*** (movement onset to target reached)
- ***Frontal*** (F3/4)
- ***Central*** (C3/4)
- ***Temporal*** (T7/7)
- ***Parietal*** (P3/4)
- ***Occipital*** (O1/2)

Processing:
1. Bandpass 8th order Butterworth filter (3-40 hz).
2. Interpolation of manually identified bad channels.
3. Resampled to 500 Hz.
4. SOBI-ICA[9] removal of eye, muscle, and noise. Execution stage only: correlated components to the IMU (-10 to 10 ms lags), identified as motion artifacts, were also removed [9-11].

Statistical Analyses
50 first and 50 last of the 200 trials are early and late practice, respectively.
- **Motor Performance metrics (MT/L):** Paired t-test of Wilcoxon signed-rank test according to distribution assessed with the Shapiro-Wilk test.
- **EEG metrics (low-/high-beta):** 2 PERIOD (Early Practice, Late Practice) x 2 HEMISPHERE (Left, Right) x 5 REGION (F, C, T, P, O) repeated measure ANOVAs. Completed for both bandwidths and stages.

Results

Motor Performance

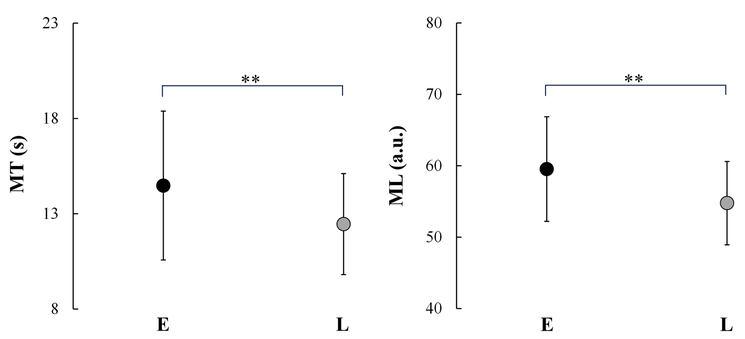


Figure 2. ***Motor Performance.*** Early (black) and late (gray) practice period for MT (left) and ML (right).

EEG

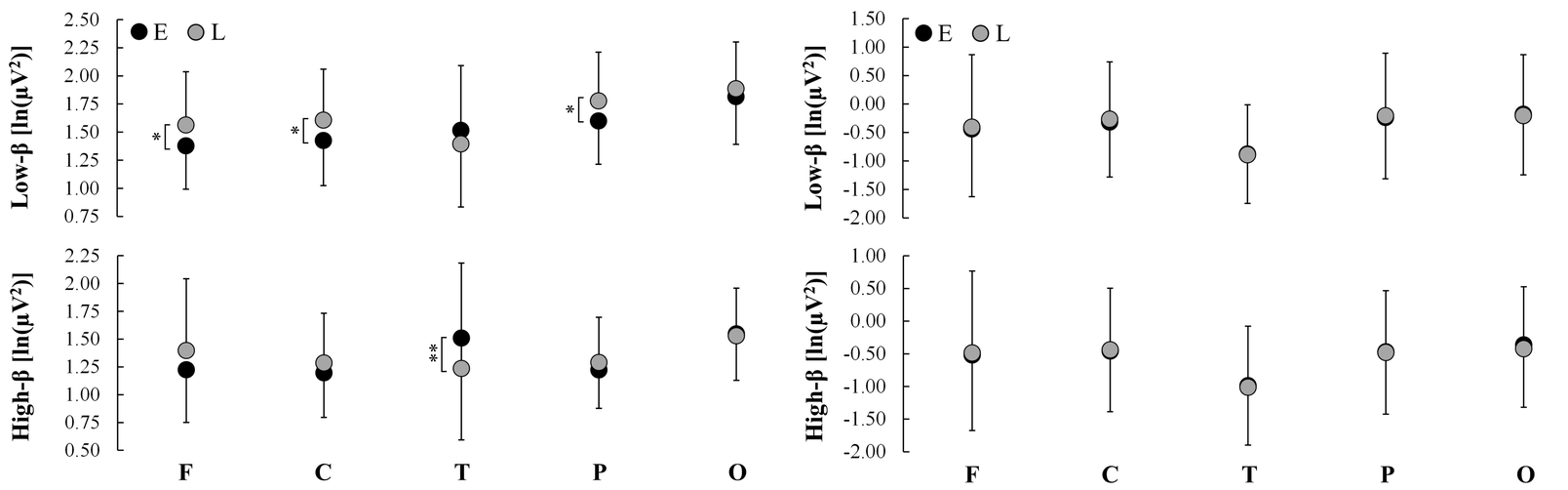


Figure 3. ***Beta Power***. Cortical regional averages of both hemispheres of early (black) and late (gray) practice period for low-beta (top row) and high-beta (bottom row) for planning stage (left) and execution state (right). F: Frontal; C: Central; T: Temporal; P: Parietal; O: Occipital

Discussion

Motor Performance :
MT and **ML** decreased.

→ **Performance Improvements Over Practice**
In-line with previous studies examining assistive systems [8,12].

EEG Planning Stage:
Low-beta increased in frontal, central and parietal regions.

→ **Central & Parietal Regions**
Encoding internal model of new sensorimotor map [13-15].

High-beta decreased in temporal region.

→ **Frontal Region**
Refinement of attentional mechanisms [4-5, 16].

→ **Temporal Region**
More engagement of memory systems at early stage of learning [17-18].

EEG Execution Stage:
Low-/high-beta had no significant changes.

→ Not in line with previous work resulting in an increase in beta[19], but suggests execution is less adaptive than planning stages and requires more practice [1].

Conclusion

Behavioral & Cortical Monitoring
Comprehensive information for therapists to utilize for their patients training. Spectral beta power could be utilized as an indicator for memory encoding during reaching tasks.

Limitations
A. Correlation between behavior and cortical activity was not done → efficiency indexing should be examined.
B. Regional information is limited → connectivity between regions should be calculated to determine if any neural networks also could be used as a biomarker of training.
C. This population encompassed individuals without disabilities → extend to clinical populations (e.g., spinal cord injury).

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