Goal-Directed Quasi-Movements Based on Natural Hand Actions: EEG Correlates and Relevance for Rehabilitation BCI

This poster

Our group

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Introduction

- Motor imagery (MI) is widely used in non-invasive BCIs, but it is internally directed and difficult to master for many patients.
- Quasi-movements (QMs) are movement attempts reduced until no movement or EMG is detectable (Nikulin et al., 2008); subjectively they can be closer to real action than MI (Yashin et al., 2023) and easier to learn (Yashin et al., this conference, poster 92).
- However, only thumb abduction QM was studied prior to this work.

Objectives:

1. Validate (offline) new, natural finger-action QMs "press" and "point"; compare with related MI.
2. Test vibrotactile feedback from the real-time QM-BCI ("press" QM).

Dive deeper into real-time QM-BCI!

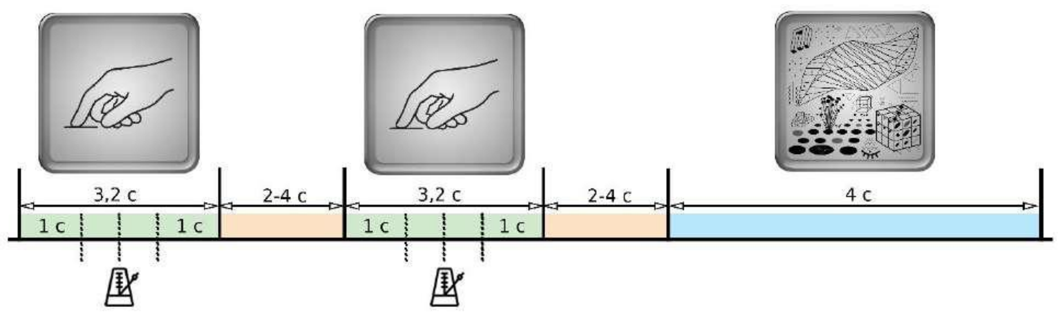
- **Wednesday** (16.9), poster **92**: Artem Yashin et al. **First Real-Time Use of Quasi-Movements for Exoskeleton Control**: Comparison with MI-BCI in Healthy Participants and Pilot Application in Stroke Rehabilitation

- **Thursday** (17.9), poster **99**: Yulia Shevtsova et al. **First real-time study of a BCI based on quasi-movements**: Comparison to the MI BCI within a new hybrid eye–brain–computer interface paradigm

Study design

1. Offline: natural QMs

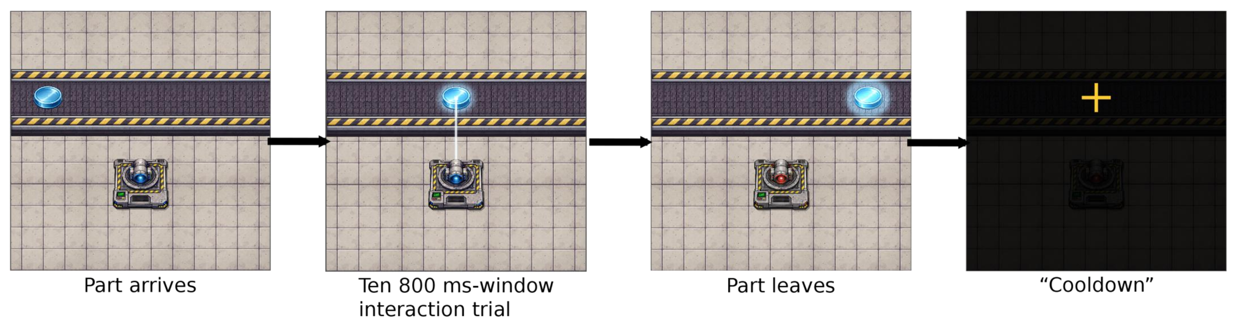
Participants: 12 healthy volunteers (21–32 y).
Actions: right index-finger pressing and pointing.
Conditions: overt movement (OM), kinesthetic motor imagery (MI), non-goal-directed QM (nQM), and goal-directed QM (gQM).
Task: three auditory cues per motor sequence (600-ms ISI), one action per cue; 20 blocks/condition.
Signal acquisition: 64-channel EEG (NVX136DC, 1 kHz) and a custom index-finger strain gauge for residual-movement monitoring.
EEG analysis: PyPREP bad-channel detection/interpolation, CSD transformation, and Morlet time–frequency analysis.
Outcomes: contralateral μ-ERD (8–13 Hz); residual movement quantified as mechanogram robust peak amplitude (RPA).
Statistics: linear mixed-effects models tested movement-type effects while accounting for RPA.



Stimulus block: two motor sequences + visual-control task.

2. Online BCI with vibrotactile feedback

Participants: 15 healthy volunteers (10 men, 5 women; 26–35 y), all experienced with MI and QM.
Design: 2 × 2 within-subject: movement strategy (MI vs QM index-finger press) × feedback (vibrotactile vs none).
Signal acquisition: simultaneous 64-channel EEG, bipolar forearm EMG, and index-finger mechanogram at 1 kHz.
BCI task: custom BCIBeam game; "good" parts required activation, "bad" parts command withholding.
Trial structure: 10 cue-locked decisions per trial, 800-ms ISI, after three preparation beeps.
Feedback: classifier-positive events triggered a visual beam and, in feedback runs, brief finger vibration.
Classifier: individualized CSP + LDA in a selected μ/α band.
Online decoding: output updated every 100 ms from a sliding 1-s EEG window; cue-level decisions used an 800-ms evaluation window.



BCIBeam task structure for a target trial.

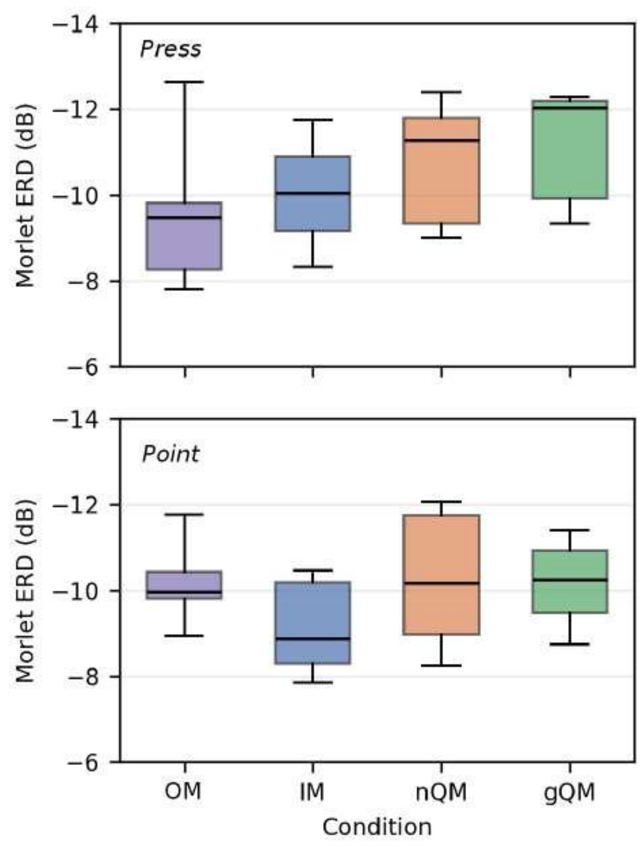
Results

1. Offline study of natural QMs

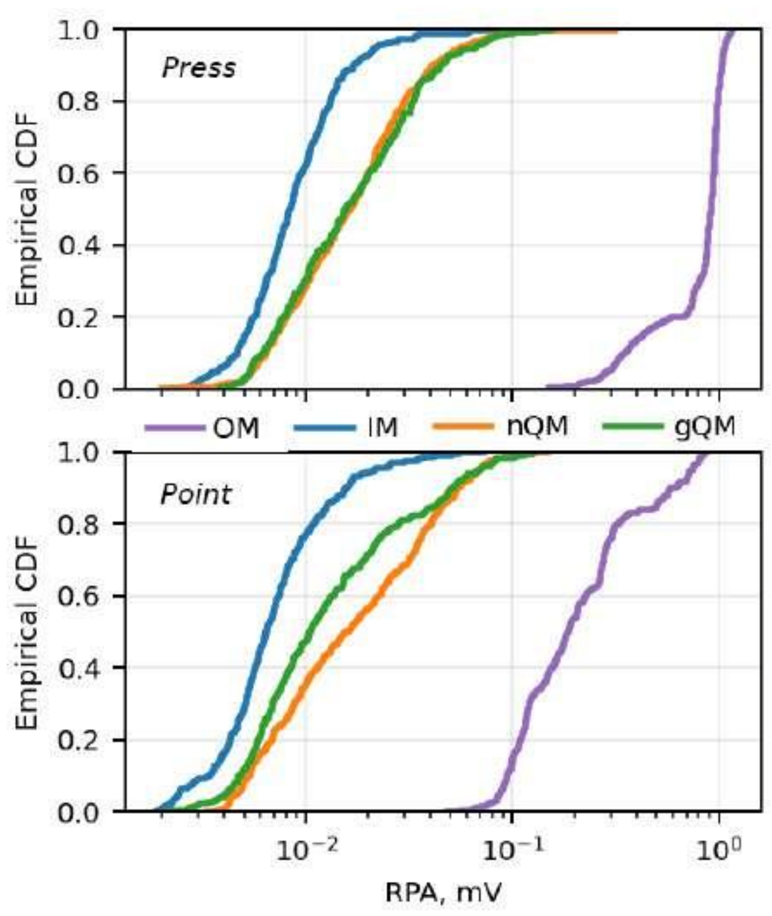
Contralateral μ-ERD (8–13 Hz) differed by movement type (p = 0.042), with QMs showing ~0.63 dB stronger ERD than MI.

ERD was stronger for pressing than pointing ($F(1,10.4)$ = 7.76, p = 0.019); for pressing, QMs also exceeded overt movement, whereas no QM-overt difference occurred for pointing.

Residual movement did not explain the stronger QM-related ERD (RPA: p = 0.973; RPA × movement type: p = 0.722).

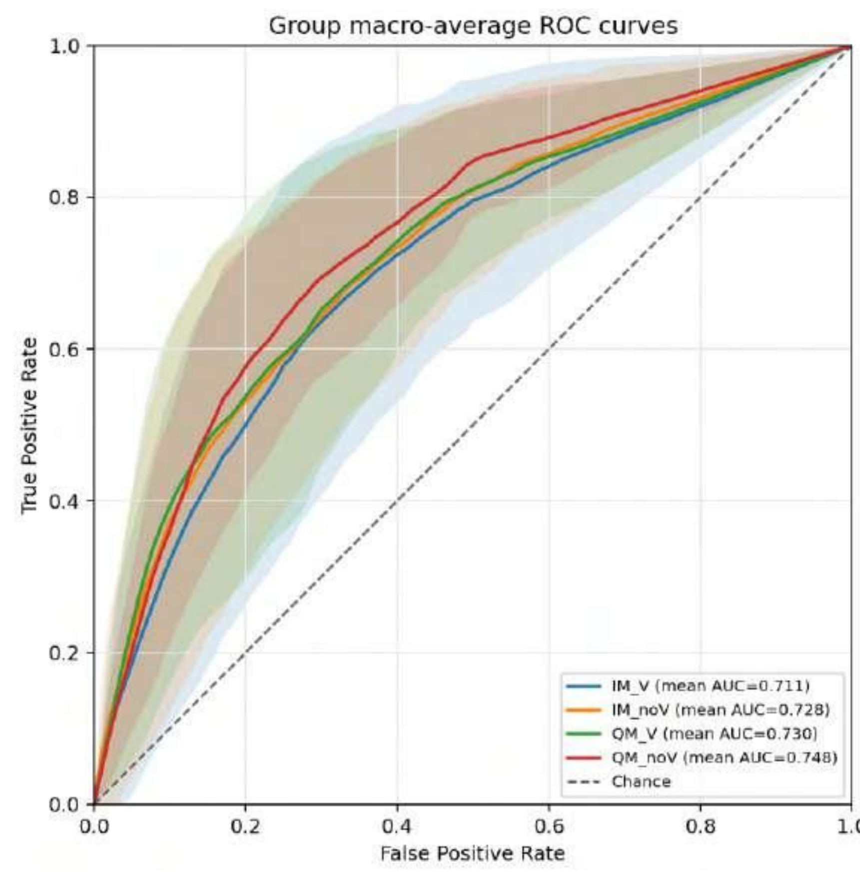


Goal-directedness. The goal-directed instruction produced no detectable additional EEG effect. nQM and gQM did not differ in upper-μ ERD (10–13 Hz) over the sensorimotor ROI (0.12 dB, p = 0.89) or in parietal α/μ ERD (8–13 Hz) (0.17 dB, p = 0.78; overall movement-type effect: p = 0.15). Thus, instructional goal-directedness was not reflected in either EEG metric.



RPA distributions confirmed that residual movement during QMs remained far below overt movement: OM produced substantially higher RPA than MI or QM during both pressing and pointing (all p < 0.001).
RPA did not differ significantly between MI and QM conditions.

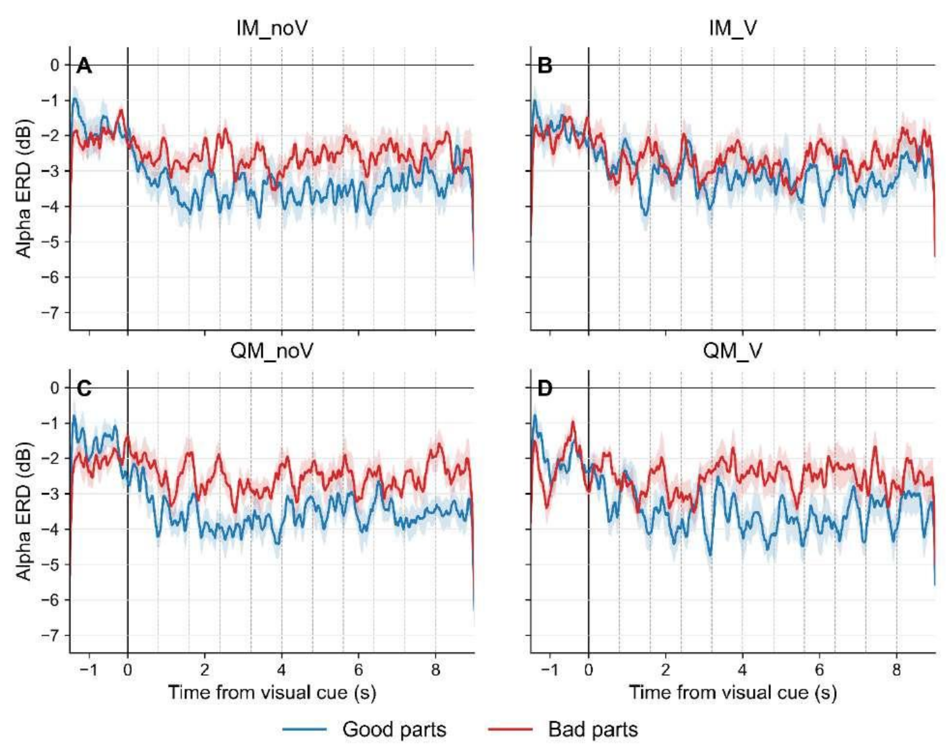
2. Online BCI control

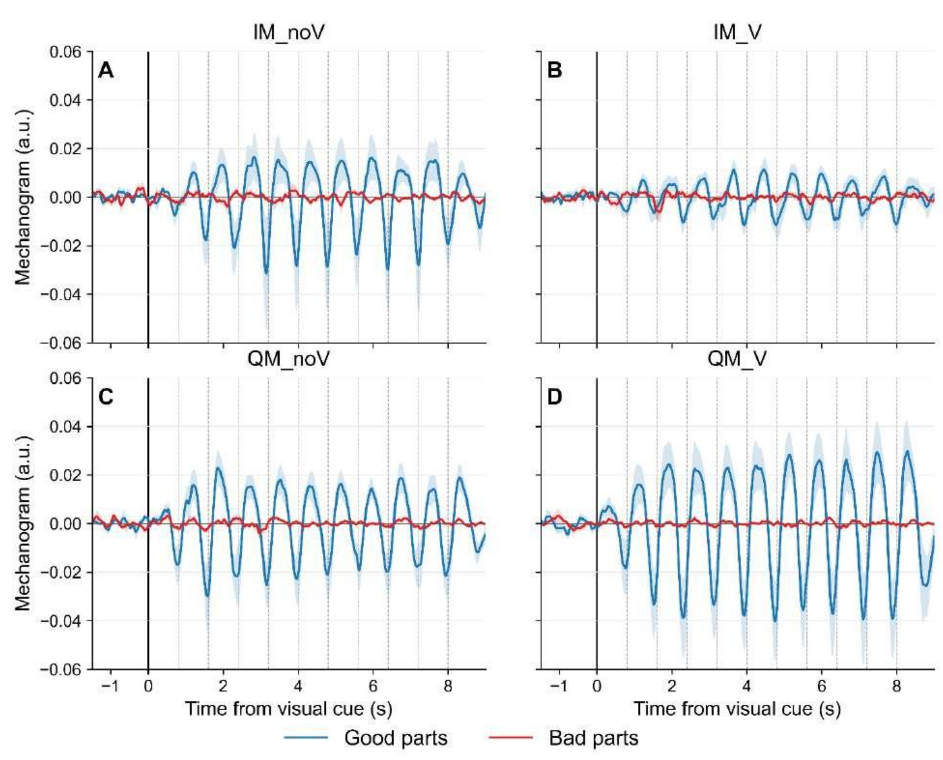


Condition	ROC AUC, mean ± SD
IM no feedback	0.728 ± 0.114
IM + feedback	0.711 ± 0.135
QM no feedback	0.748 ± 0.075
QM + feedback	0.730 ± 0.115

Online BCI performance. Both MI and QM supported successful online control, with very similar ROC curves across the four conditions.
Neither movement strategy, vibrotactile feedback, nor their interaction significantly affected ROC AUC (p = 0.424, 0.272, and 0.975, respectively).

Sensorimotor α-ERD. Target trials showed sustained contralateral α-ERD, but mean ERD did not differ between MI and QM or between feedback conditions. Thus, the stronger QM-related ERD observed offline was not reproduced during online BCI control.





Peripheral activity differed between MI and QM in the mechanogram, but not in EMG. EMG RMS showed no effect of movement strategy (p = 0.700). In contrast, mechanogram RPA was higher for QM than MI overall (p = 0.0085). This difference depended on feedback (movement × feedback: p < 0.001): QM > MI with vibrotactile feedback (p = 0.0005), whereas the difference was not significant without feedback (p = 0.195).

General conclusions

- **Natural-action quasi-movements are feasible** for pressing and pointing and produce robust sensorimotor activation while overt movement remains strongly suppressed.
- In the offline study, QMs showed **stronger contralateral μ-ERD than MI**, not explained by residual movement.
- Goal-directed instructions produced no additional EEG effect in upper-μ ERD in sensorimotor and parietal areas.
- **Online QM-BCI performance was comparable to MI**, although the stronger offline QM-related ERD was not reproduced online.
- MI and QM differed in some aspects of residual muscle activity, but not in mean α-ERD or decoding performance; brief vibrotactile feedback **did not improve either**.
- Overall, QMs remain promising as a **rehabilitation-oriented alternative to MI and a model of attempted movement**.

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