First Real-Time Use of Quasi-Movements for Exoskeleton Control: Comparison with MI-BCI in Healthy Participants and Pilot Application in Stroke Rehabilitation

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This poster

1 Introduction

Background

Kinesthetic motor imagery (MI). Used in post-stroke rehabilitation with a BCI. A non-trivial skill, hard to teach within clinical time constraints [1, 2]

Motor attempts (MA). More natural and intuitive, but in patients they may provoke side effects [3, 4]: spasticity, abnormal synergies, frustration

Quasi-movements (QM). Movement attempts minimised until EMG responses vanish, yet with pronounced EEG effects [5, 6]. Never used in rehabilitation before; can be learned on the unaffected hand and are expected to cause fewer side effects. Abnormal synergies are effort-dependent [7]

Aims

Study I. Compare QM- and MI-based BCI control of hand exoskeletons in healthy participants

Study II. Transfer the QM protocol to chronic stroke patients and test the feasibility of repeated QM-BCI training in a clinical setting

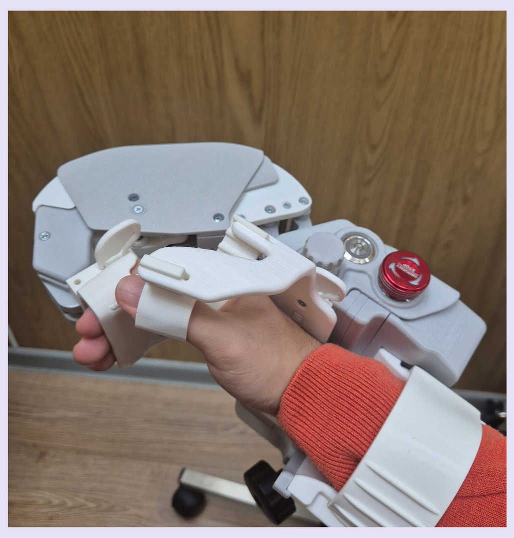
STUDY QUESTION

Can movement attempts minimised to the point of vanishing EMG drive a rehabilitation exoskeleton in real time?

2 Setup & BCI Procedure

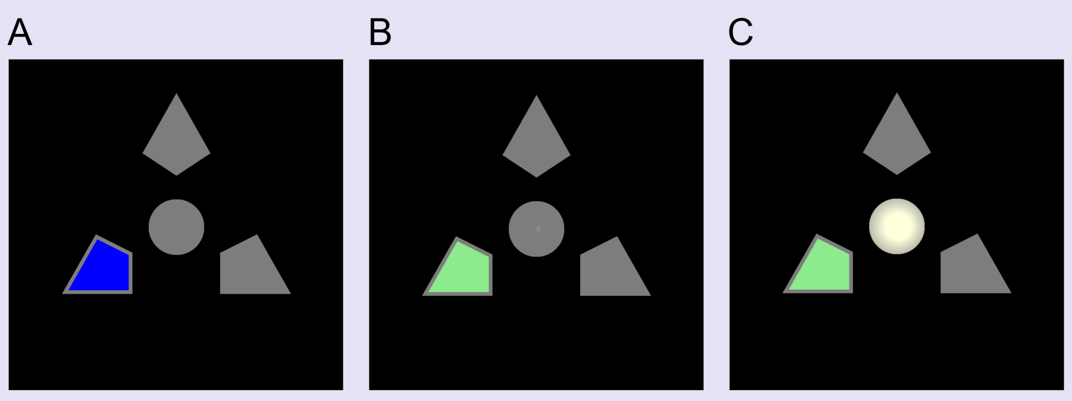
Exoskeletons

Kinesthetic BCI feedback came from the ExoHand-M exoskeletons: opening speed was set by the probability of the target class [8]; the hand opened only while that class was detected



BCI Session Structure

4 blocks per session – block 1 for classifier training, blocks 2-4 online. Each block contained 8 trials per motor class (left / right hand) plus 16 rest trials



On-screen cues for preparation (A), execution (B) and feedback (C). Arrows defined trial type; brightness of central circle tracked classifier probability

Classification. CSP (4 components per class pair) + shrinkage-regularised LDA on 1 s windows advanced in 250 ms steps; the classifier was retrained after every block

3 Study I – Healthy Participants

Hypotheses, Participants & Design

H1 – QM-based control yields higher three-class accuracy than MI-based control

H2 – QM-based control is perceived as more effective and more comfortable than MI-based control

Sample. 19 healthy participants (1-33 years, median 22), 14 right-handed; no previous experience with MI, QM or BCI

Equipment. EEG – 64 electrodes (NVX136 amplifier), 52 used for online classification, impedance below 20 kΩ. EMG - 2 bipolar forearm channels

Design. Repeated measures – 3 conditions (QM / MI / passive movement [PM]) × 2 sessions, in randomised order

Questionnaires. Continuous scales after each session (success, difficulty, monitoring of muscle tension, task–device compatibility, sense of control), between-condition comparisons at the end, and a binary preference question

Statistics. Two-way repeated-measures ANOVA over conditions and sessions; post-hoc t-tests with FDR correction

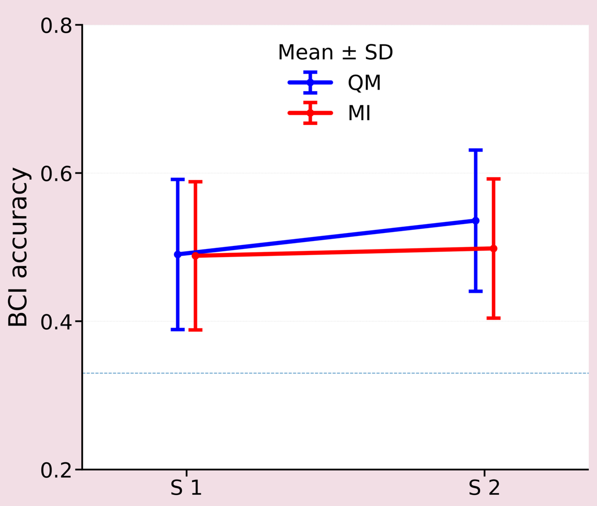
Training in QM & MI

QM. Overt hand opening was gradually reduced in amplitude under EMG monitoring, refined into attempts without visible movement or EMG response, then transferred to the other hand

MI. Kinesthetic descriptors were elicited with a finger-extension resistance device, synthesised into a kinesthetic image and rehearsed with both hands

Duration. About 15 min per task, before the main experiment

Three-class Online Classification Accuracy

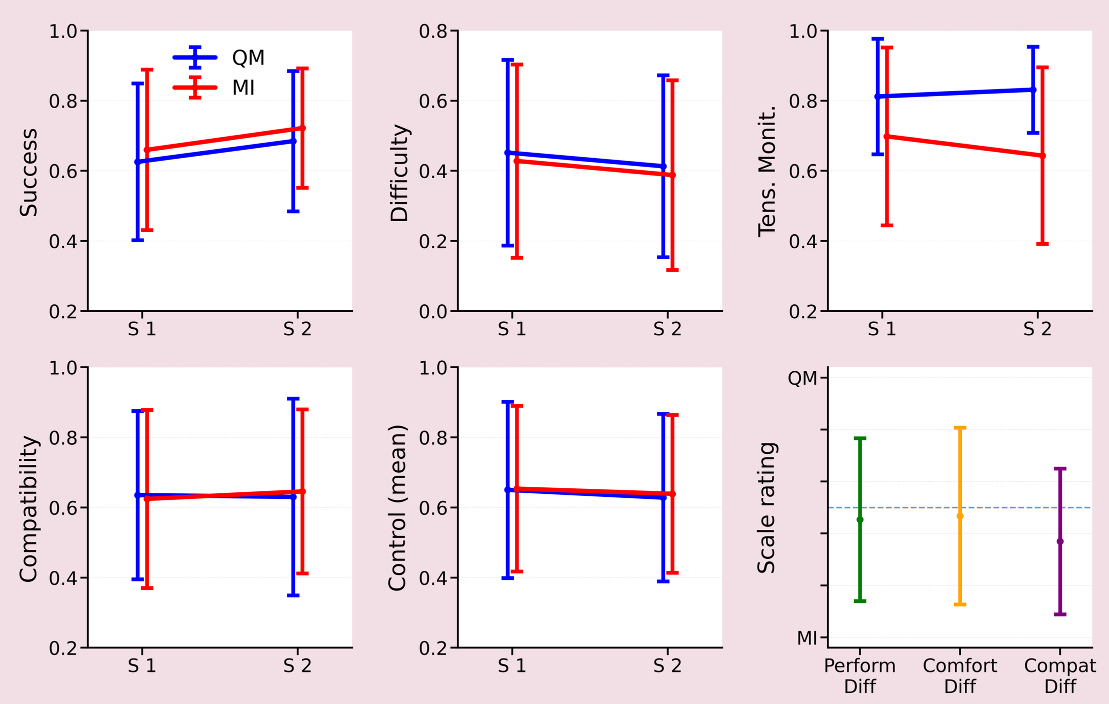


Accuracy did not differ between QM and MI – both modes give exoskeleton control of comparable quality

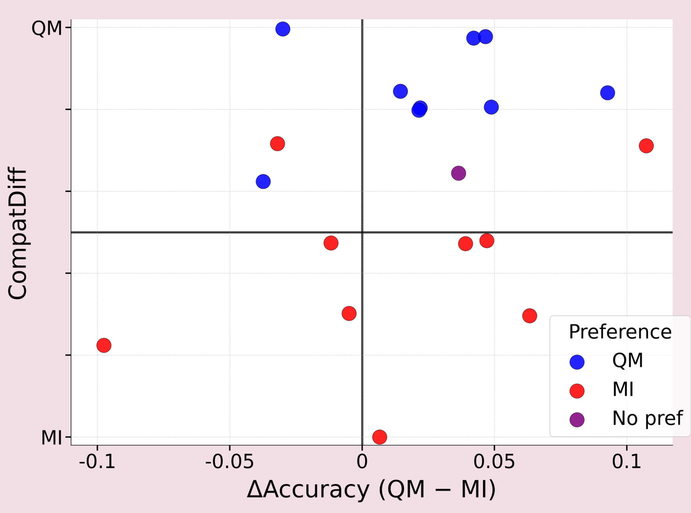
H1 was not supported

dashed line = theoretical chance level (1/3)

Subjective Ratings



Only monitoring of muscle tension differed in QM vs MI (higher for QM, p = 0.01). H2 was not supported



Binary preference judgements plotted against the QM-MI difference in BCI accuracy and in the compatibility rating

Judgments were divided 9 : 9 between QM and MI, plus one undecided participant

EMG – Residual Muscle Activity

	QM 1	QM 2	MI 1	MI 2	PM 1	PM 2
Right hand, online	3.62 ± 2.66	3.77 ± 3.18	4.19 ± 4.51	3.60 ± 3.27	1.60 ± 1.37	1.00 ± 0.25
Right hand, training	1.06 ± 0.24	1.61 ± 1.46	1.12 ± 0.27	1.27 ± 0.51	1.14 ± 0.28	1.05 ± 0.36
Left hand, online	2.80 ± 2.15	2.43 ± 1.40	2.62 ± 2.43	2.34 ± 2.05	1.39 ± 0.78	1.33 ± 0.99
Left hand, training	1.44 ± 1.01	1.44 ± 0.55	1.02 ± 0.22	1.22 ± 0.56	1.27 ± 0.90	1.14 ± 0.54

Rest-normalised RMS (M ± SD); 1.0 = rest. RMS was higher in online than in training. Exoskeleton motion induced contractions during both tasks

4 Study II – Stroke Patients

Patients & Recording Equipment

Patients. 4 patients with ischaemic stroke (2 f, 2 m; 46-73 years), all right-handed with right-hemisphere lesions; two with severe and two with moderate paresis. Time since stroke: 48, 11, 7 and 4 months

Equipment. EEG – 32 electrodes (NVX-52 amplifier), all used for classification. EMG – finger extensors and finger flexors

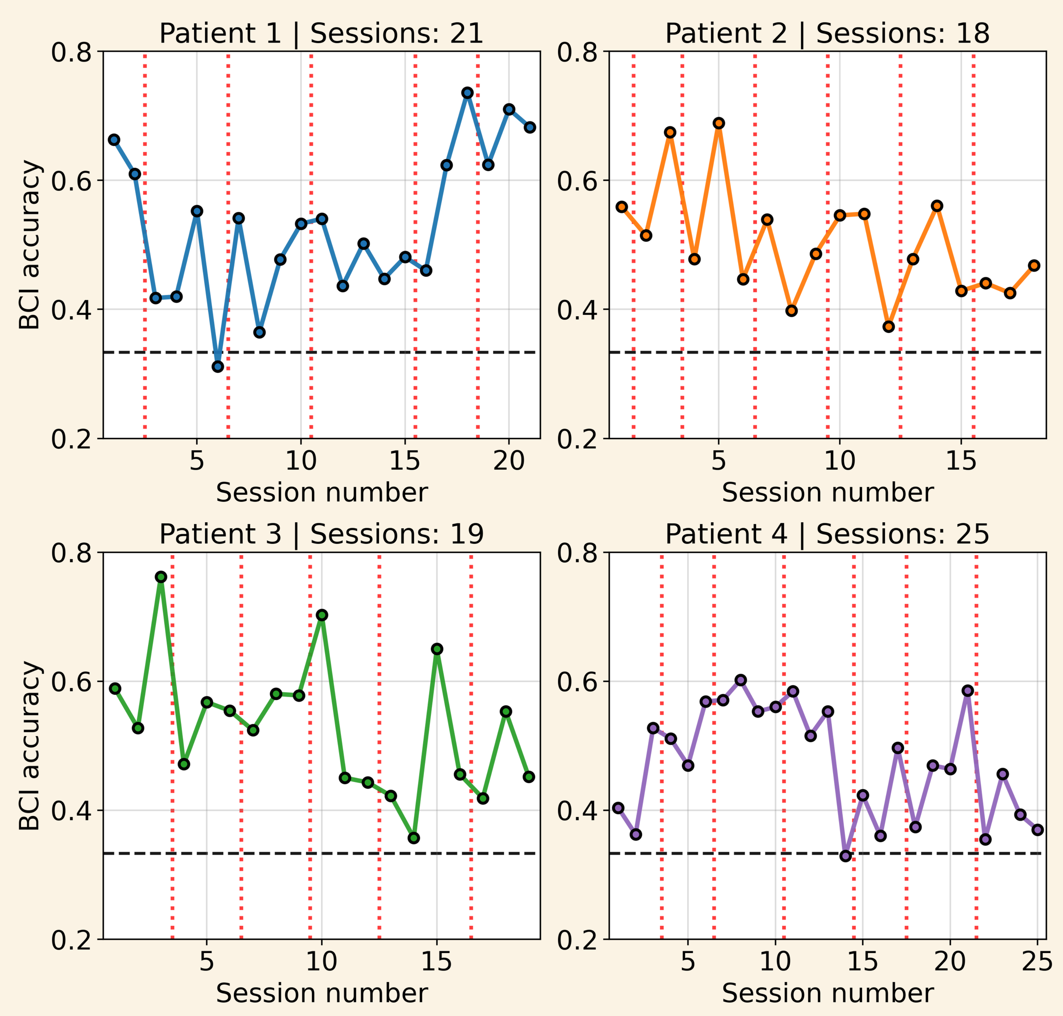
Protocol

QM training. Shortened and adapted to limit fatigue: gradual reduction of amplitude with the healthy hand (complete EMG suppression was not required) → the same minimised task with the paretic hand. The whole procedure took only a few minutes

Design. MI was not tested in patients, to avoid task confusion and extra cognitive load in a cognitively vulnerable sample

Course. 6-7 days, 3-5 sessions per day depending on the patient's condition

BCI Accuracy across Sessions



Mean accuracy across all sessions: 0.53 ± 0.12 (Patient 1), 0.50 ± 0.09 (Patient 2), 0.53 ± 0.10 (Patient 3), 0.47 ± 0.09 (Patient 4)

KEY RESULT

All four patients grasped the QM instructions within minutes and stayed above the nominal three-class chance reference throughout the course

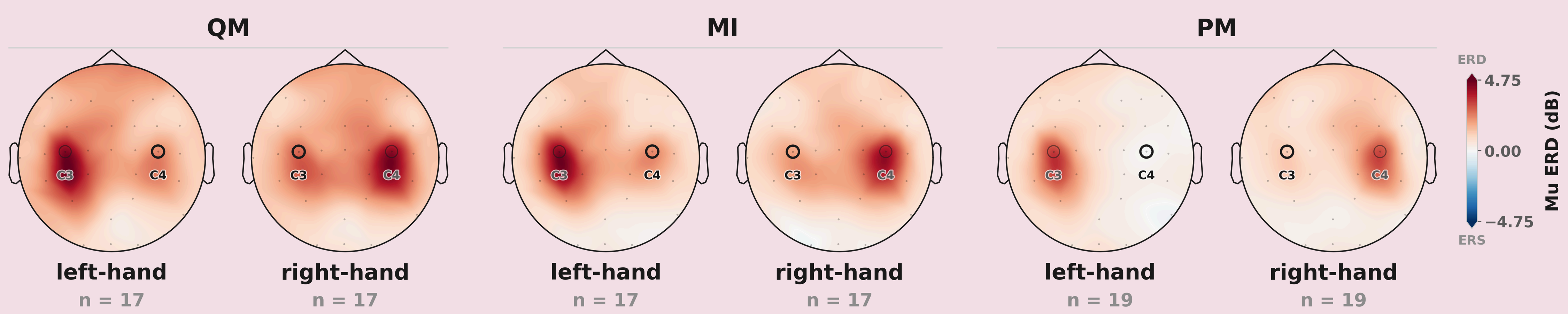
Clinical Scales

Assessment	At admission Mdn (range)	At discharge Mdn (range)
MMSE	25 (22–28)	n/a
MoCA	23.5 (18–25)	25 (23–28)
FMA-UE	29 (11–54)	35 (12–58)
HADS anxiety	8 (3–19)	7.5 (3–17)
HADS depression	5.5 (2–9)	5 (2–13)
Barthel Index	95 (70–100)	97.5 (95–100)

Change from admission to discharge was heterogeneous but generally favourable (note: no statistical tests performed). The clearest shifts were in upper-limb motor function; MoCA rose by 2.75 points on average, moving patients out of the dementia range. HADS changed little

Sensorimotor Mu Suppression

[Paired t-tests] Right-hand (C3): QM > PM (p = 0.029), Left-hand (C4): QM > PM (p = 0.019), MI > PM (p = 0.005)



5 Conclusions

Comparable accuracy. QM and MI produced similar online classification accuracy (H1 not supported)

Similar subjective experience. Conditions differed only in the monitoring of muscle tension: QM were not perceived as less difficult or more compatible with exoskeleton control (H2 not supported)

Clinically feasible. Patients grasped the QM instructions within minutes and stayed above chance across 6–7 days; clinical change was heterogeneous but generally favourable, although the results are preliminary

An additional strategy. Preferences split almost evenly – QM widens the set of tasks available for personalised BCI rehabilitation

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