Modulation of Cortical Excitability by Detection of Motor Intention and Artificial Afferent Feedback

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Outline

BRAIN SIGNALS

AFFERENT INPUT TRIGGERED BY CORTICAL POTENTIALS EVOKED BY MOTOR IMAGINATION

STROKE REHABILITATION
BRAIN SIGNALS

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STROKE REHABILITATION
BCI Operation Characteristics

• Interaction of two adaptive controllers
  – User produces signals that encode a message
  – BCI translates signals into device commands
  – A new skill that both systems acquire and maintain
BCI Applications for communication/restoration/replacement of function

- Communication
- Environmental control
- Robotics / Mobility devices
- Neuroprosthetics
- Neuromodulation
• A negative EEG deflection preceding and accompanying self-paced voluntary real and imaginary movements.

• MRCP amplitude is related to force and speed.
Movement-Related Cortical Potential (MRCP)
Movement-Related Cortical Potential (MRCP)


Upper limb:
Wrist rotation/extension
Gu et al Clin Neurophysiol 2009
• Focus on BCI for neuromodulation

• MRCPs as control signals (detection of movement intention)

• Control of artificial afferent feedback by MRCPs
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STROKE REHABILITATION
Paired associative stimulation (PAS)

Pre-measures – TMS alone

Intervention – peripheral nerve stimulus + TMS

Post-measures – TMS alone
Effects following PAS are:

- **dependent on the timing between the two stimuli**
- specific to the target muscle
- rapidly evolving
- persist upon cessation of the stimulation period

For a comprehensive review refer to Ziemann et al. (2008)
PAS: Classic paradigm

Pre-measures – TMS alone

Intervention – peripheral nerve stimulus + TMS

Post-measures – TMS alone
A new intervention based on brain activity

Pre-measures – TMS alone

Intervention – peripheral nerve stimulus + Imagery

Post-measures – TMS alone

Pre-measures – TMS alone

Intervention – peripheral nerve stimulus + Imagery

Post-measures – TMS alone

Mrachacz-Kersting et al. J Physiol 2012
MRCP-triggered stimulation: Effect of delay

3 Interventions at least 2 days in between
Duration = 30 min

2 x 25 pairs

PRE

× 16

POST

× 16

Mrachacz-Kersting et al. J Physiol 2012
Experimental set-up

Focus Time  

Preparation Phase

Task  

Hold Phase

Inter-Trial Rest Phase

A

B

C

Computer

EEG

EMG

Electrical Stimulator

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Representative MEPs

Prior to PN

At PN

After PN

n = 1

0.5 mV

50 ms
Intervention 1: Prior to PN = PN (ms) – SD (ms) – 50ms

Mrachacz-Kersting et al. J Physiol 2012
Intervention 2: At PN = PN (ms) - 50ms (time for ES to reach MCx)

[Graph showing TA MEP amplitude vs. TMS intensity for pre- and post-intervention conditions, with early readiness potential phase (RP) and Boltzman fit lines.]
Intervention 3: After PN = PN (ms) + SD (ms) − 50ms

TA p-p MEP amplitude vs. TMS intensity [%S.O.]

Early readiness potential (RP) phase

Boltzman fit pre-intervention
Preset fit post-intervention

Pre-intervention
Post-intervention

Mrachacz-Kersting et al. J Physiol 2012
Control experiments

- Imagination only
- Electrical stimulation only
- Visual attention and electrical stimulation
- Spinal excitability
• The intervention uses self-generated physiological signals for inducing plastic changes within the motor cortex

• Timing is critical

• Online detection of MRCP with small latency needed
Can MRCPs be detected from single-trial EEG?

- Raw 9 Channels
- Pre-processed 9 Channels
- Test set 9 Channels
- Training set 9 Channels
- Spatial filtering
- Template
- Template Matching
- Detection

Optimal spatial filter (SNR)

Niazi et al. J Neural Eng. 2011
Method

- Optimized spatial filter applied to incoming EEG data to obtain surrogate channel

- Matched Filter: Correlation between testing set surrogate channel and template

Niazi et al. J Neural Eng. 2011
Detection latency

Latency (s)

Subjects

Niazi et al. J Neural Eng. 2011
Subject-specific training is not needed

The detection accuracy when using an average template from a database of subjects on new subjects is only \(~2\%-3\%\) lower than with a subject specific template (Niazi et al, Med Biol Eng Comput 2012)
• MRCPs can be detected online with 80% true positives and less than 10 false positives in 5 min

• Latency is on average ~ -50 ms

• No need for a subject specific training

• This allows the development of a full online, self-paced system
Self-paced imagination

- Computer
- EEG
- EMG
- Electrical Stimulator
Online detection and stimulation at peak negativity

Electrical stimulation at peak negativity
Asynchronous Imagery

TMS intensity [%S.O.]

35 40 45 50 55 60 65

TA p-p MEP amplitude [V]

0 1000 2000 3000 4000 5000

pre-intervention

post-intervention

Boltzman fit pre-intervention

Boltzman fit post-intervention

Subject 1

Subject 2

Group Data (TA muscle)

** P<0.05
* P>0.05

% Improvement in TAMEpmax

N=8
N=4
N=4

BCI
Control 1: self-paced
Control 2: random ES only

• Online detection has sufficient accuracy and sufficiently small latency for inducing plastic changes

• Fully self-paced system

• Possibility for clinical studies

• Functional relevance ?
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STROKE REHABILITATION
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<th>Age, years</th>
<th>Gender</th>
<th>Time after stroke, months</th>
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<th>mRS score</th>
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Stability of the MRCP (one patient)

Amplitude of MRCP \[ \mu \text{V} \]

-6 -4 -2 0 2 4 6

Day 1 MRCP
Day 2 MRCP
Day 3 MRCP

Onset of imagined dorsiflexion task

500 ms

Niazi et al. In Preparation
Detection latency in patients

Subjects

Latency of PN (mS)

Niazi et al. In Preparation
Changes in motor evoked potential (MEP) following the intervention (3 weeks, 3 times per week)

TMS intensity [%S.O.]

TA p-p MEP amplitude [V]

pre-intervention
post-intervention
30min post-intervention

Niazi et al. In Preparation
Changes in motor evoked potential (MEP) following the intervention (3 weeks, 3 times per week)

Niazi et al. In Preparation
Statistics and control conditions

TA MEPmax amplitude [% pre-intervention]

CPN+lateCNV
CPN+ME
CPN+HP
Imagery alone
TN+ME
Watching only

n = 9
n = 9
n = 9
n = 8
n = 9
n = 4

* Niazi et al. In Preparation
• MRCP’s stability is confirmed in stroke patients

• MEP amplitude increased significantly following the intervention

• Functional improvement (10 m walk)

• Applications in robot-aided rehabilitation
Control of robotic devices with MRCPs
Detection of gait initiation

Standing plate contact identification

Sway identification
Step initiation detection by MRCPs

Jiang et al. In Preparation
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