Water immersion modulates sensory and motor cortical excitability

Daisuke Sato, PhD

Department of Health and Sports

Niigata University of Health and Welfare

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Topics

- **Neurophysiological changes during water immersion**
- **Neural plasticity induced by water immersion**

Neurophysiological changes in WI

WI could induce several physiological changes;

- **Cardiopulmonary;** venous return, SV / HR, residual volume etc
- **Hormonal activity;** catecholamine, noradrenaline etc
- **Muscle activity;** antigravity muscle
- **Autonomic nervous system;** sympathetic nerve / parasympathetic nerve

Neurophysiological changes in WI

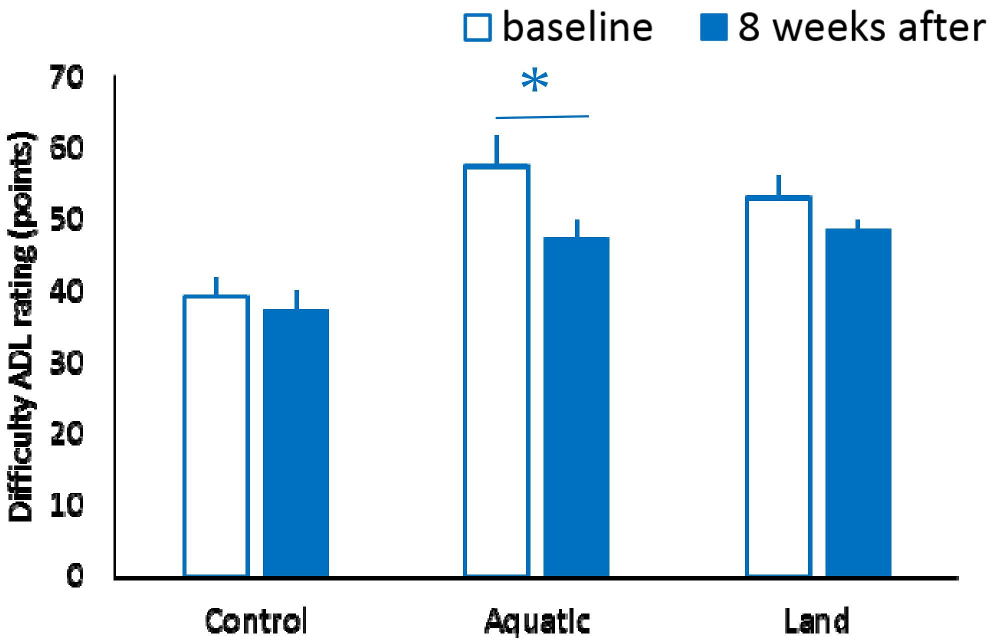
Therapeutic intervention for health promotion and rehabilitation;

- **Hypertension patients** Wilson et al., Hypertension, 2009
- **Chronic obstructive pulmonary disease** Kurabayashi et al., Am J Phys Med Rehabil, 2000
- **Osteoarthritis patients** Suomi et al., Arch Phys Med Rehabil, 2000
- **Stroke patient** Yoo et al., Ann Rehabil Med, 2014
- **Frail elderly people** Sato et al., Quality of Life res, 2007, Disabil Rehabil, 2009

Neurophysiological changes in WI

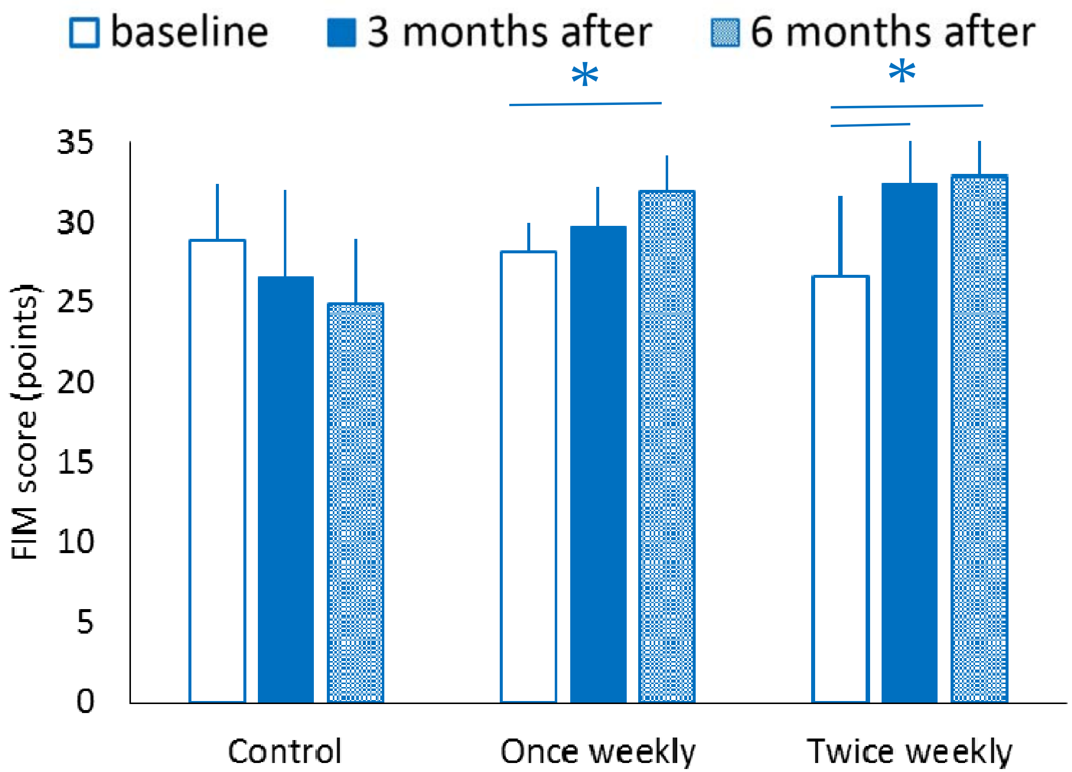
- **Change in movement;**

Personal care, physical mobility, transfer, and shopping and yard work



Suomi et al., *Arch Phys Med Rehabil*, 2003

Transfer, mobility, and stair climbing

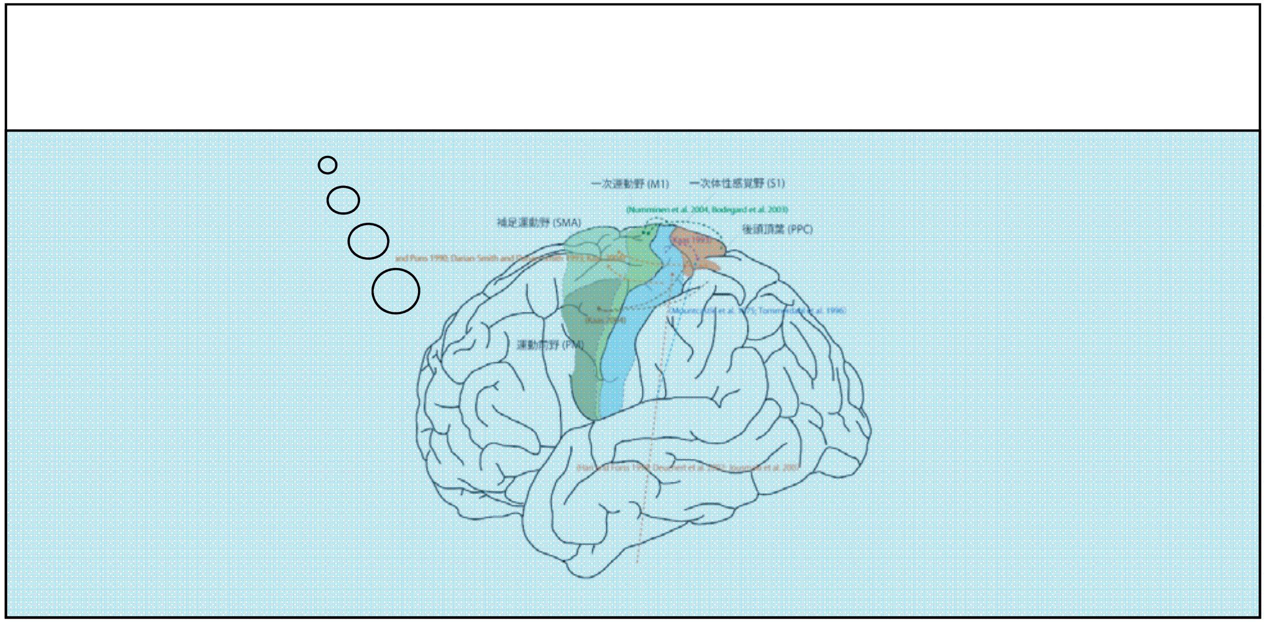


Sato et al., *QOL research*, 2007

aquatic exercise affects some movements and motor learning

Research Question

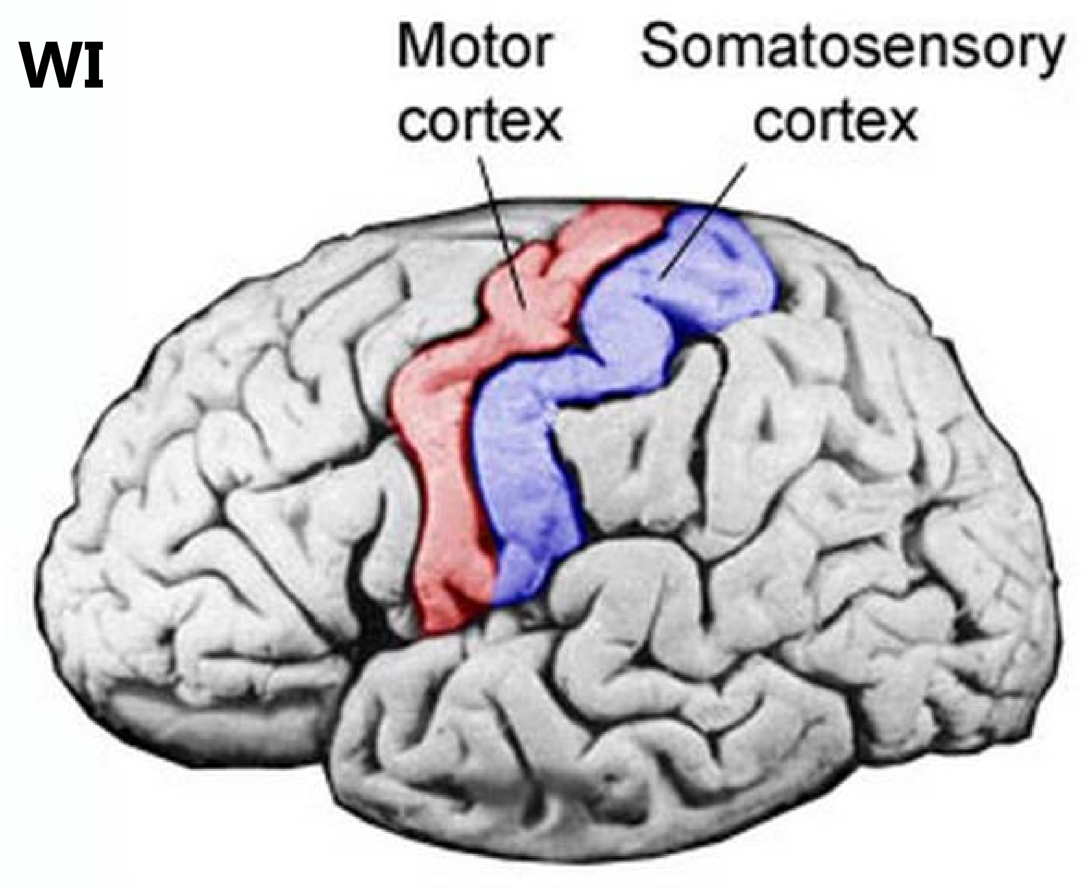
Does water immersion affect Central Nerve Activity?



Does water immersion affect neural activity?

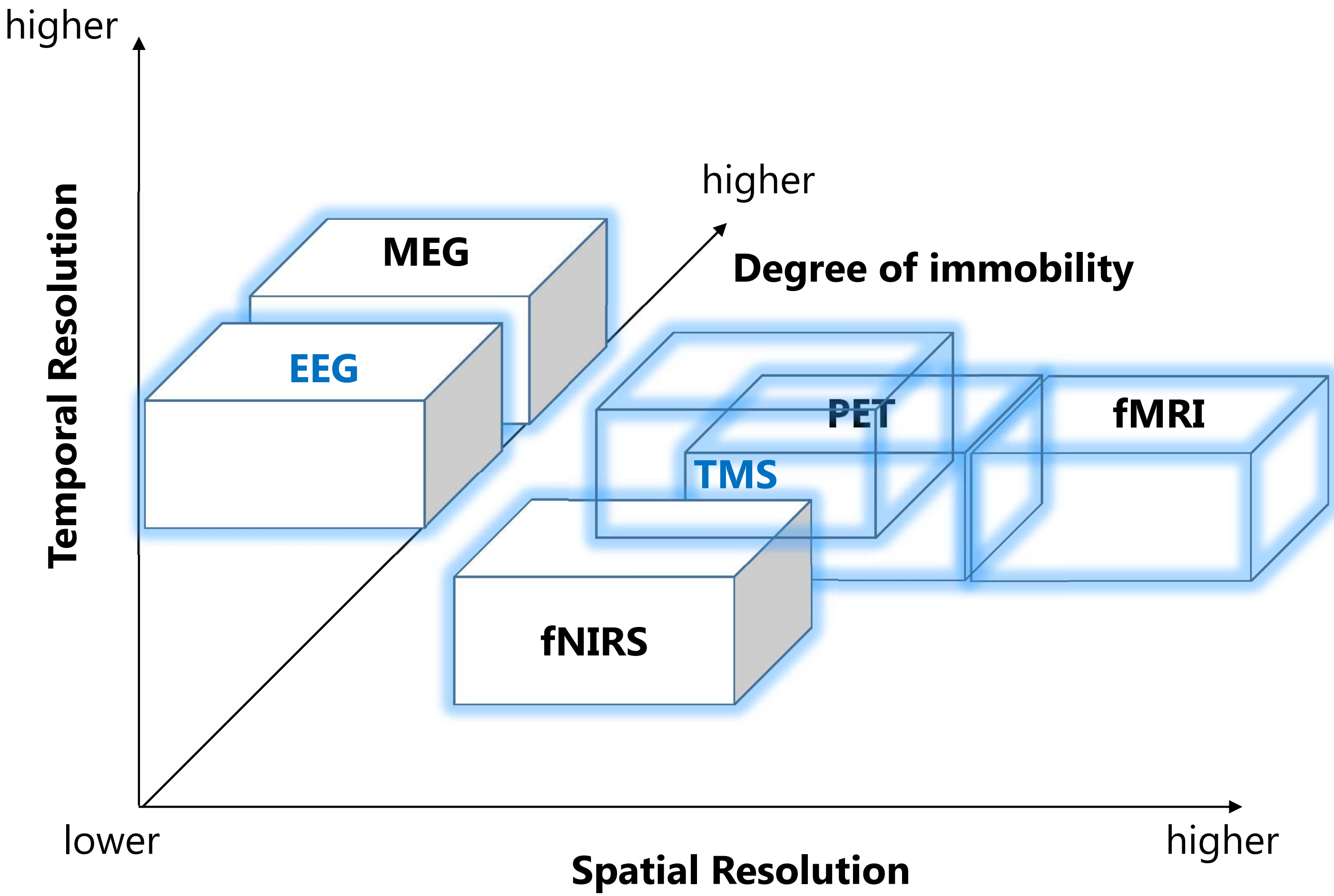
Somatosensory input during WI

- Tactile
- Pressure
- Vibration
- Warm
- Cold



Does water immersion affect neural activity?

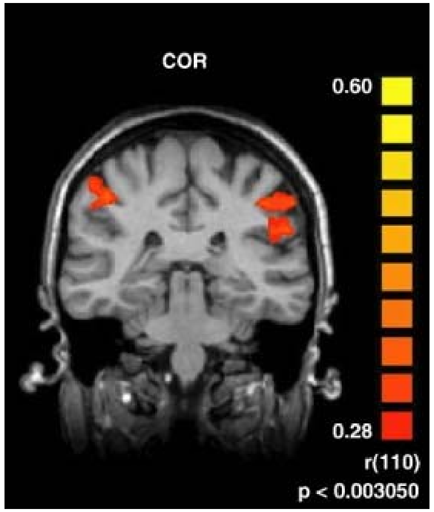
- **EEG**
- MEG
- fMRI
- PET
- fNIRS
- **TMS**



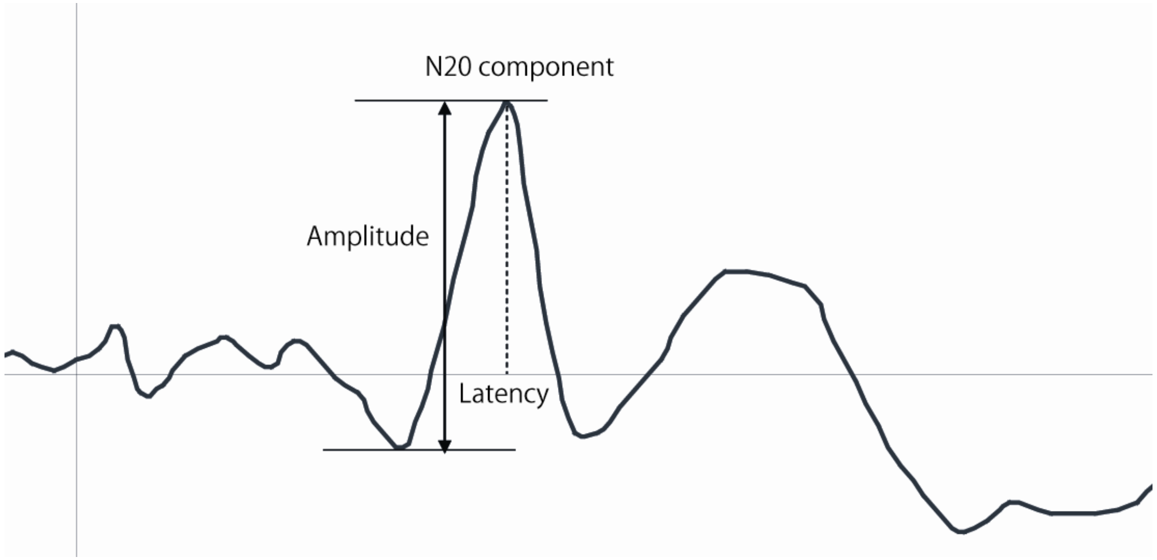
Mehta et al. Front Hum Neurosci 2013 doi: 10.3389/fnhum.2013.00889

Does water immersion affect neural activity?

- **Investigate the excitability of S1 during WI using EEG**
- **S1 carries out the first stage of cortical processing of somatosensory input**
- **Water temperature 30℃ / axillary level**

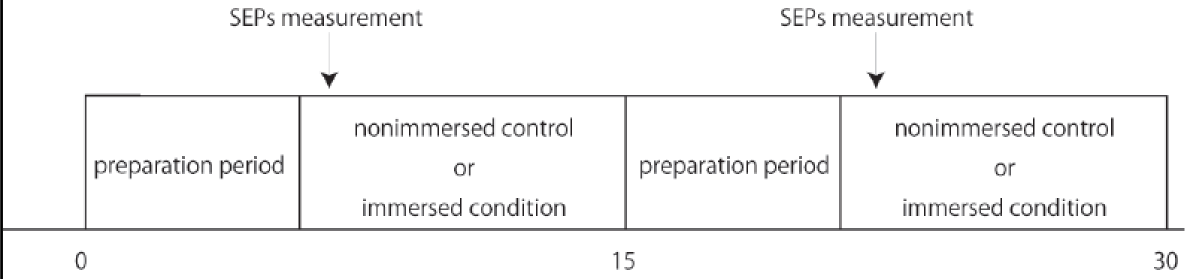


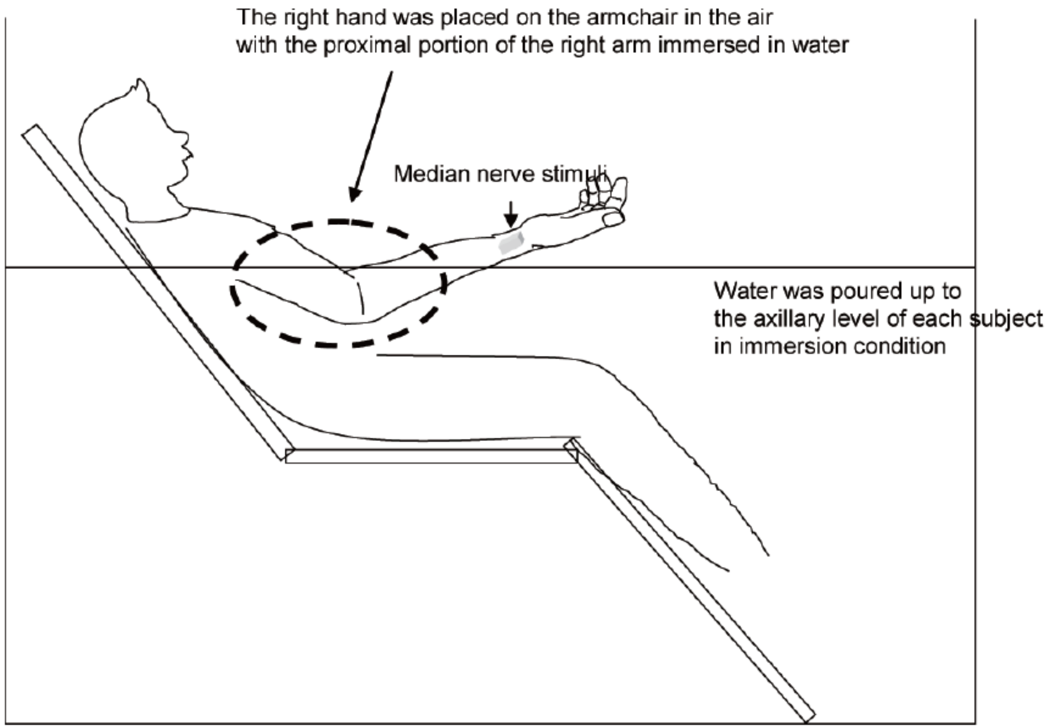
Blatow et al. Neuroimage 2007



Does WI attenuate short SEP?

- **SEP measurement were conducted in water and on land in random order**





Sato et al. BMC neurosci 2012

Does WI attenuate short SEP?

- **Smaller amplitude were seen in P27 and P45 components**
- **These component reflects activation of S1 (and PPC)**

Allison et al. Brain 1991

Inui et al. Cerebral Cortex 2004

WI might affect primary somatosensory cortical excitability

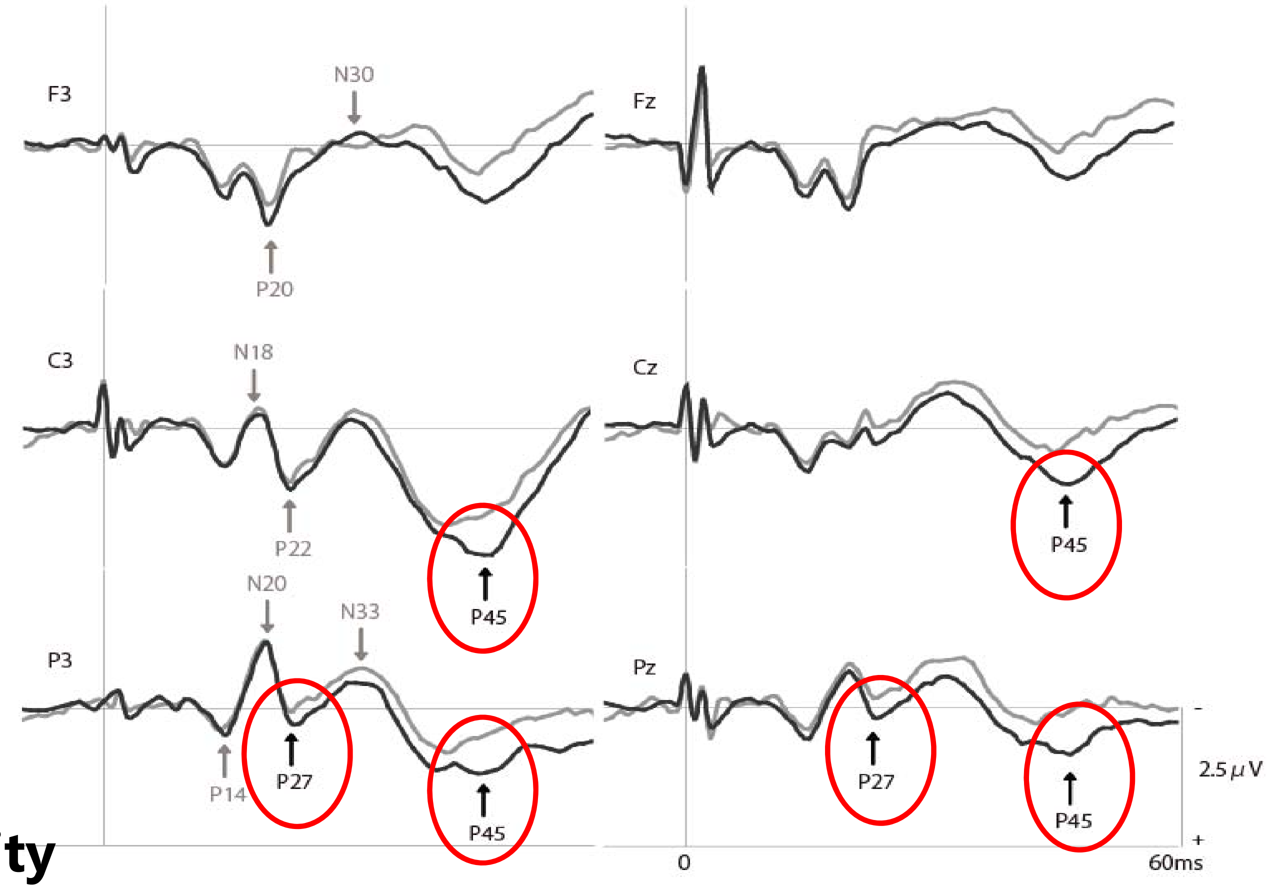


Figure. SEP waveform in water and on Land

Sato et al. BMC neurosci 2012

Mechanism of SEP attenuation

- Afferent inhibition; the neural activity of S1 induced by interfering stimuli
  - ✓ Continuous rubbing to the palm; P25 and P29
  - ✓ Soft nylon brush to palm; P22 and P27

Schmidt et al. Exp Brain Res 1990
Jones et al. Elecrroencephalogr Clin Neurophyiol 1985

- Surround inhibition; the neural activity of S1 by afferent input from several body area
  - ✓ Tactile stimuli to various part of the body

Tinazzi et al. Brain 2000
Kakigi et al. Elecrroencephalogr Clin Neurophyiol 1985

somatosensory input from wide area by water immersion induce the activation in wide area of somatosensory area

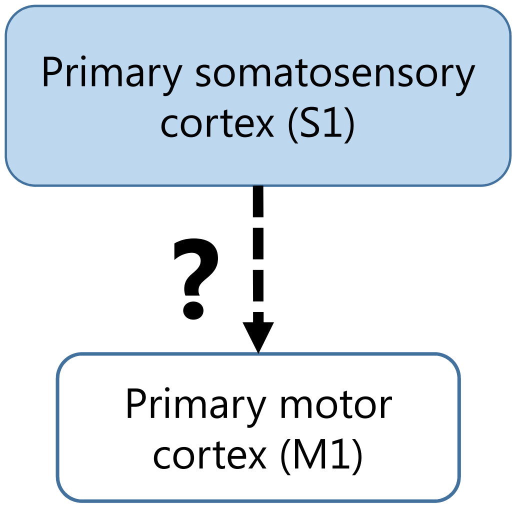
The findings from SEP study

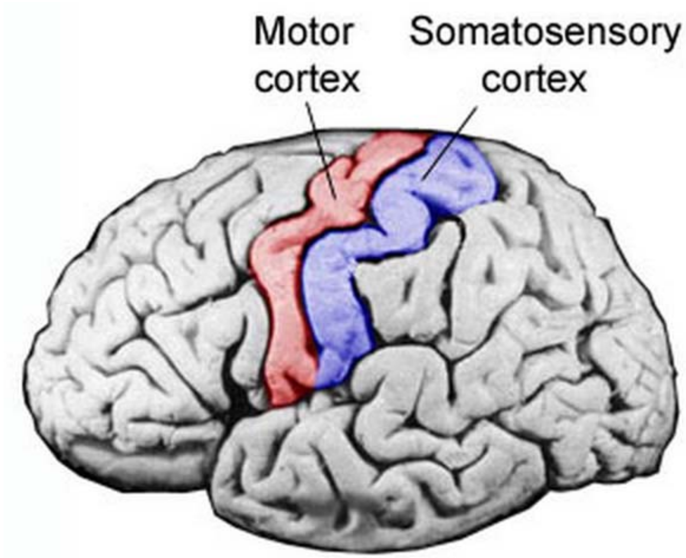
- WI changes the cortical processing for somatosensory input
- WI seems to induce neural activities in somatosensory area

How about primary motor cortex (M1)?

- Strong neural connection between S1 and M1
- Somatosensory input changes M1 excitability

Maertens de Noordhout et al. J Physiol 1992, Ridding et al. J Physiol 2001; Rossini et al. Muscle Nerve 1996





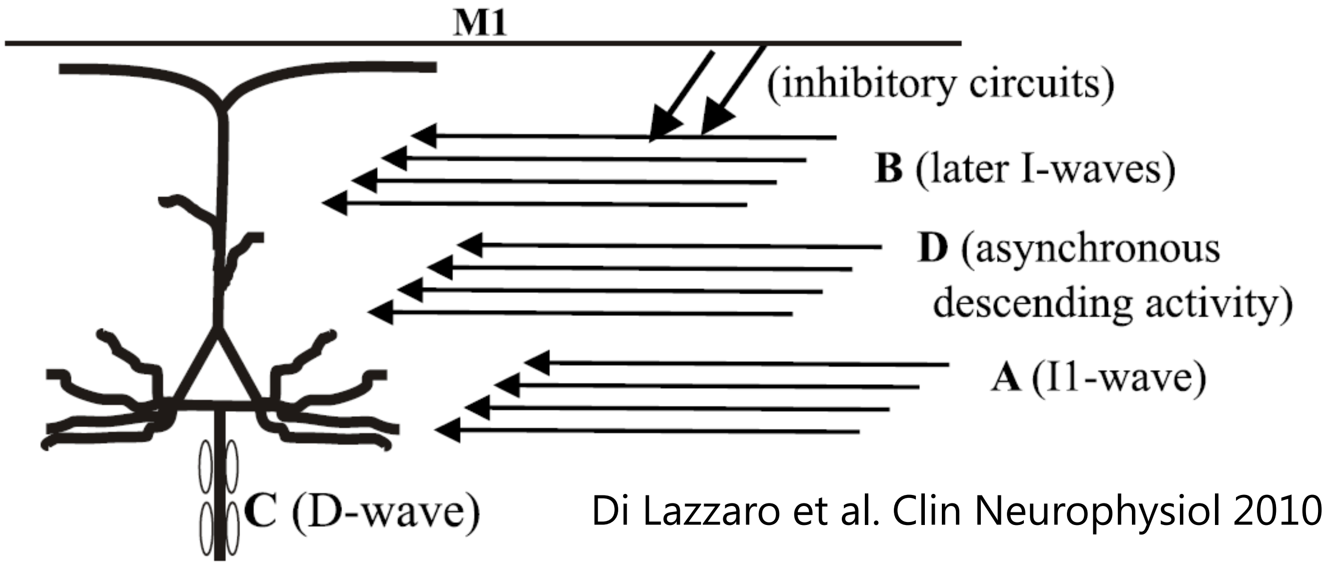
Transcranial Magnetic Stimulation (TMS)

- Noninvasive technique for the functional evaluation of the M1 in human

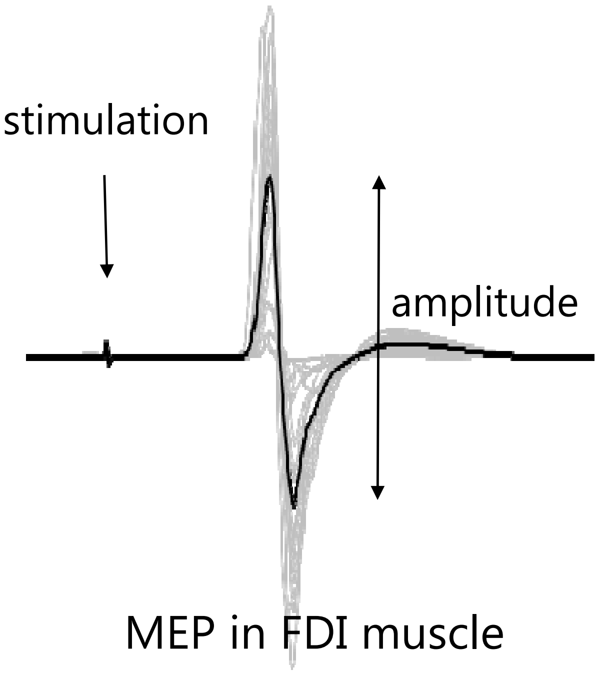
Transcranial Magnetic Stimulation (TMS)

- TMS can stimulate several interneurons input to pyramidal neuron in M1
- Neural excitability were evaluated by MEPs in muscle

Excitatory circuits activated by transcranial magnetic stimulation



Di Lazzaro et al. Clin Neurophysiol 2010



MEP in FDI muscle

Intracortical excitability in M1

- **Paired-pulse paradigm**

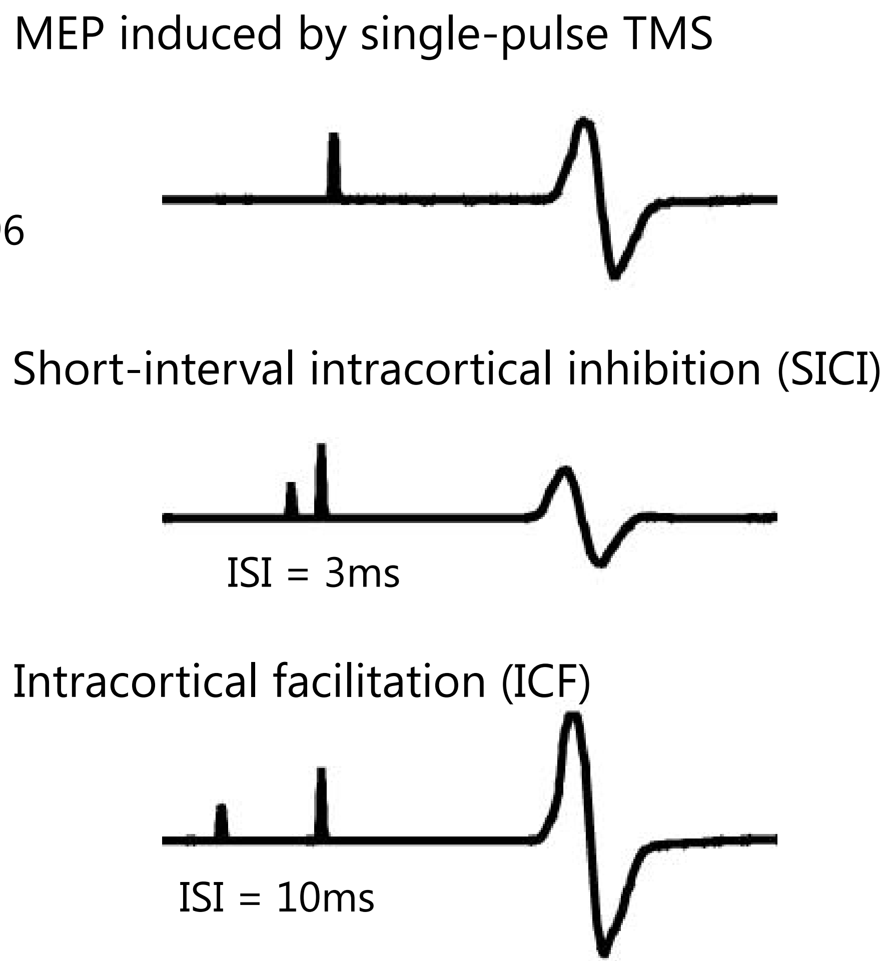
  Kujirai et al. J Physiol 1993, Ziemann et al. J Physiol 1996

- **Motor learning**

  Rosenkranz et al. J Neurosci 2007

- **NIBS plastisity**

  Murase et al. Brain Stimulation 2015



Sensorimotor integration

- **pairing of single TMS pulses with peripheral electrical**

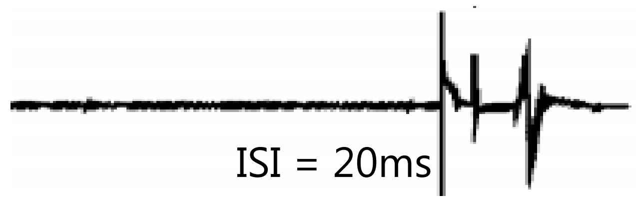
Chen et al. Exp Brain Res 1999, Tokimura et al. J Physiol 2000

- **Evaluate the activity of cholinergic neurons input to inhibitory circuit**

Di Lazzaro et al. J Neurol Neurosurg Psychiatry 2005

MEP induced by single-pulse TMS

Short latency afferent inhibition (SAI)



Long latency afferent inhibition (LAI)

Sailer et al. Brain 2003

How about primary motor cortex (M1)?

- **Cortico-spinal excitability**
- **SICI, ICF, SAI,LAI**

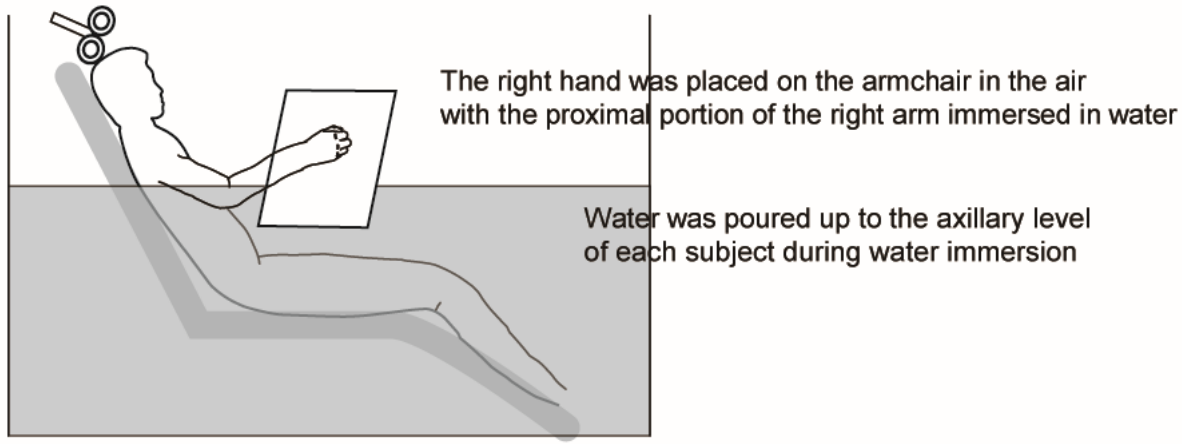
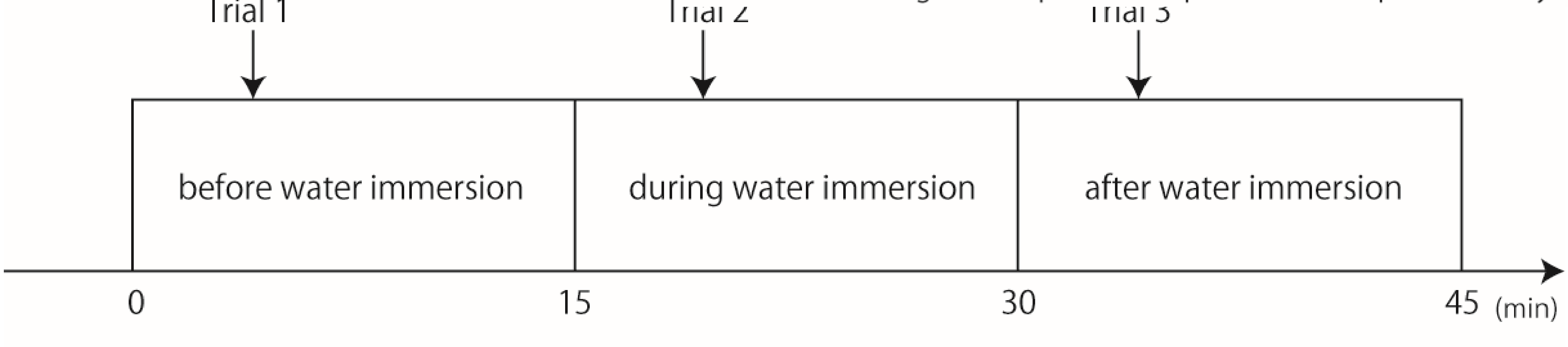
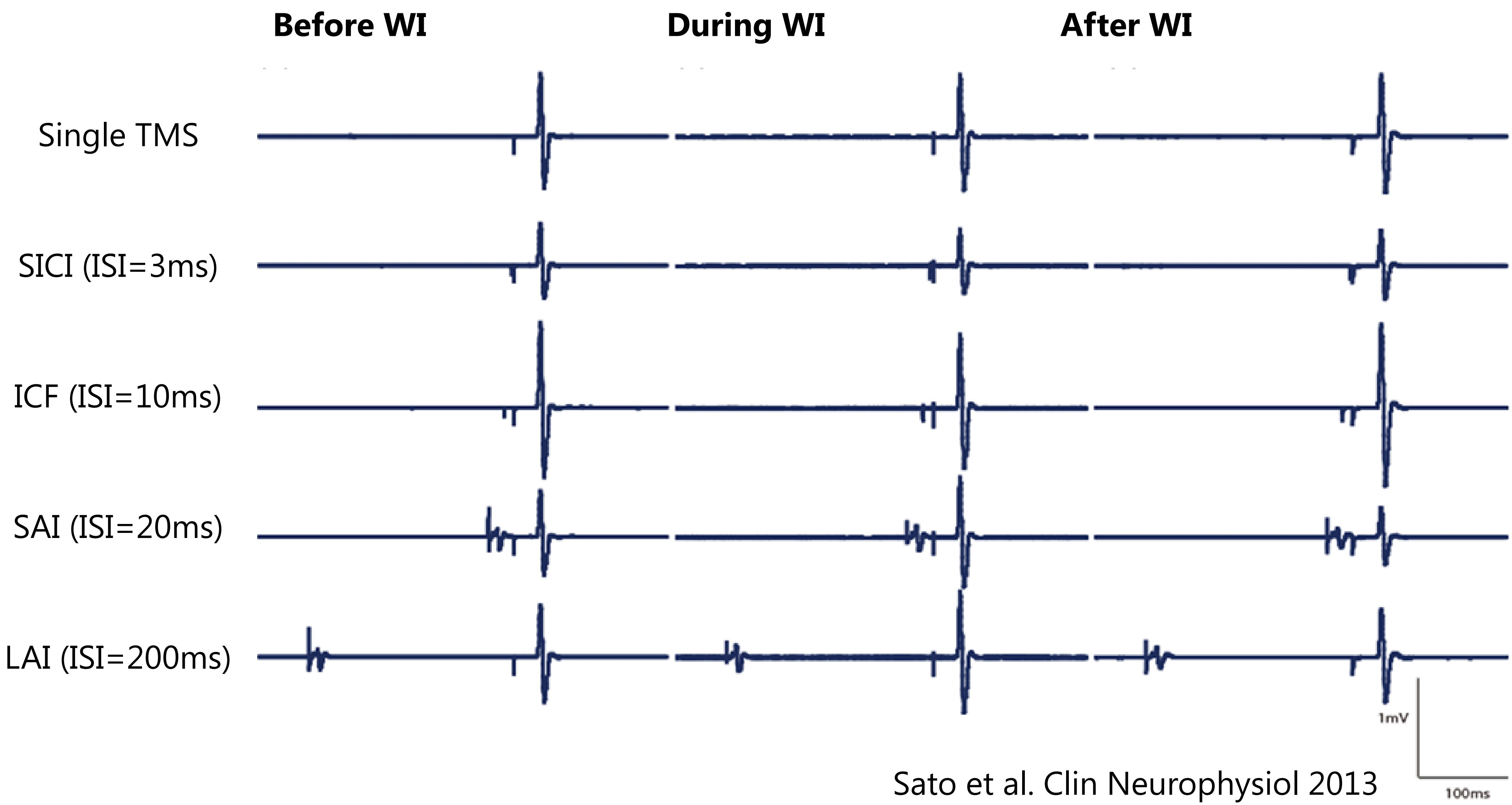


Figure 1. Experimental protocol in the present study.



How about primary motor cortex (M1)?



Sato et al. Clin Neurophysiol 2013

How about primary motor cortex (M1)?

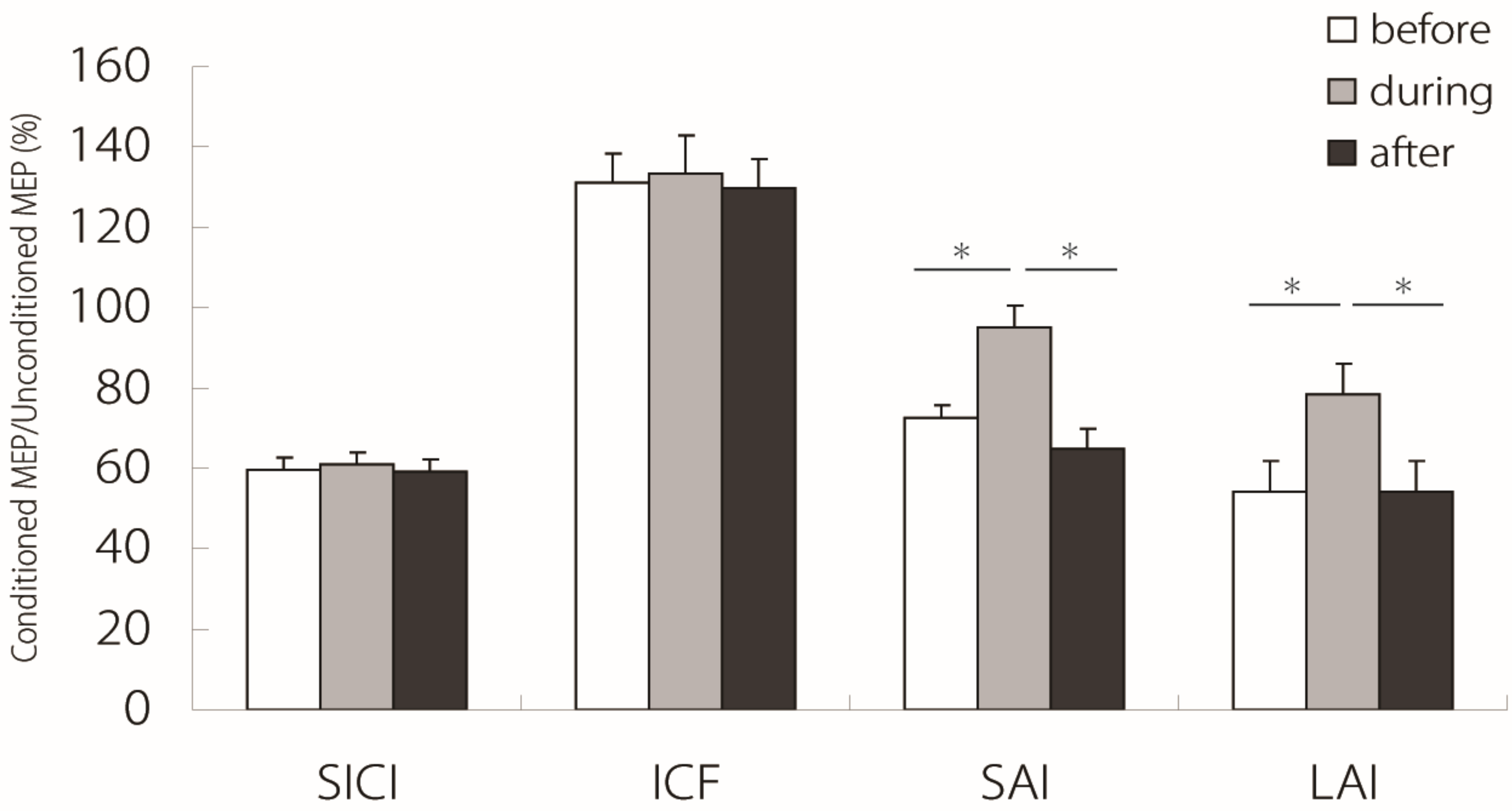


Figure 4. Short interval intracortical inhibition (SICI), intracortical facilitaion (ICF), short latency afferent inhibition (SAI) and long latency afferent inhibition (LAI) before, during and after water immersion.

Sato et al. Clin Neurophysiol 2013

No change in M1 excitability

- **afferent inputs from proximal skin and muscle spindles increase the MEP amplitudes induced by TMS in relaxed hand**

Rosenkranz et al. J Physiol 2003, Exp Brain Res 2003, Terao et al. Clin Neurophysiol 1995, Brain 1999

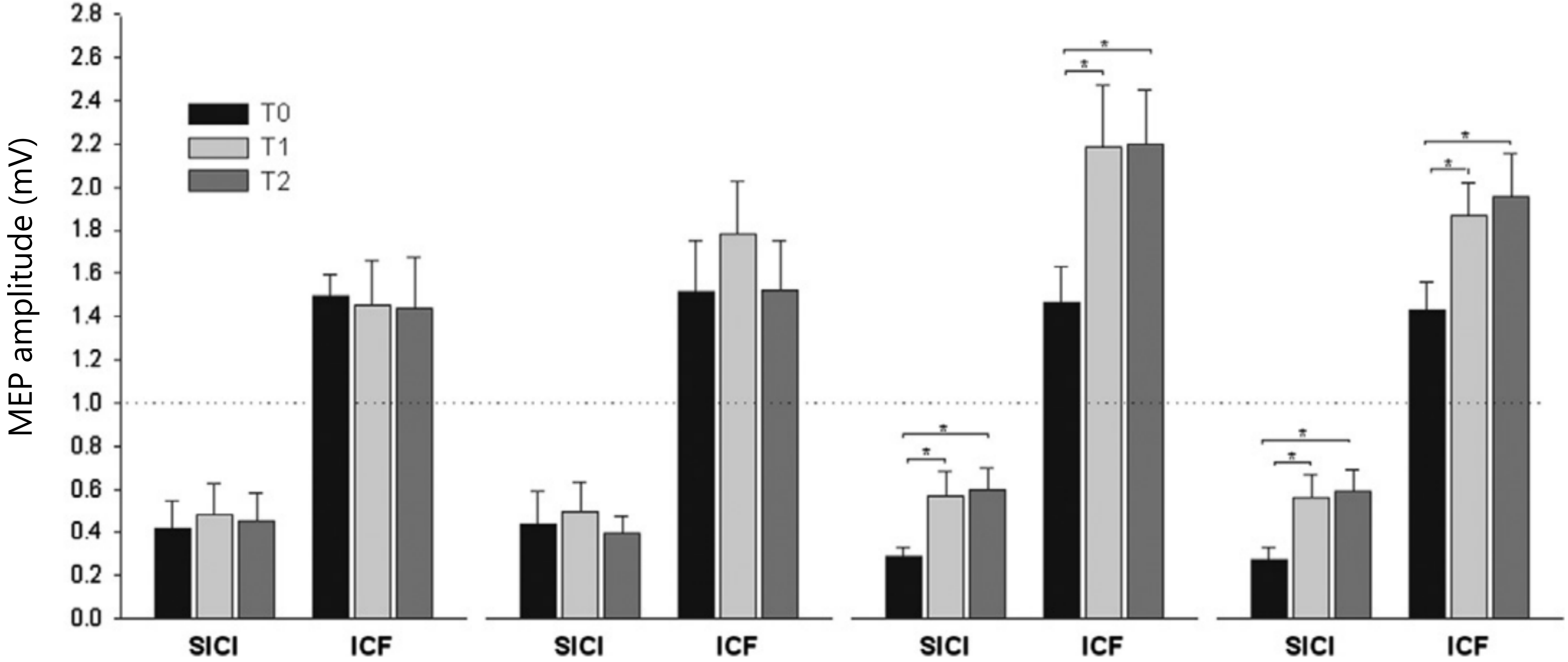
✓ **stimulus intensity and frequency** Golaszewski et al. Clin Neurophysiol 2012

✓ **modality of afferent input; skin or muscle spindle**

Rosenkranz et al. J Physiol 2003

✓ **Stimulus site** Ridding et al. Exp Brain Res 2005

No change in M1 excitability



Control

Low intensity (sensory)
Low frequency (2Hz)

Low intensity (sensory)
High frequency (50Hz)

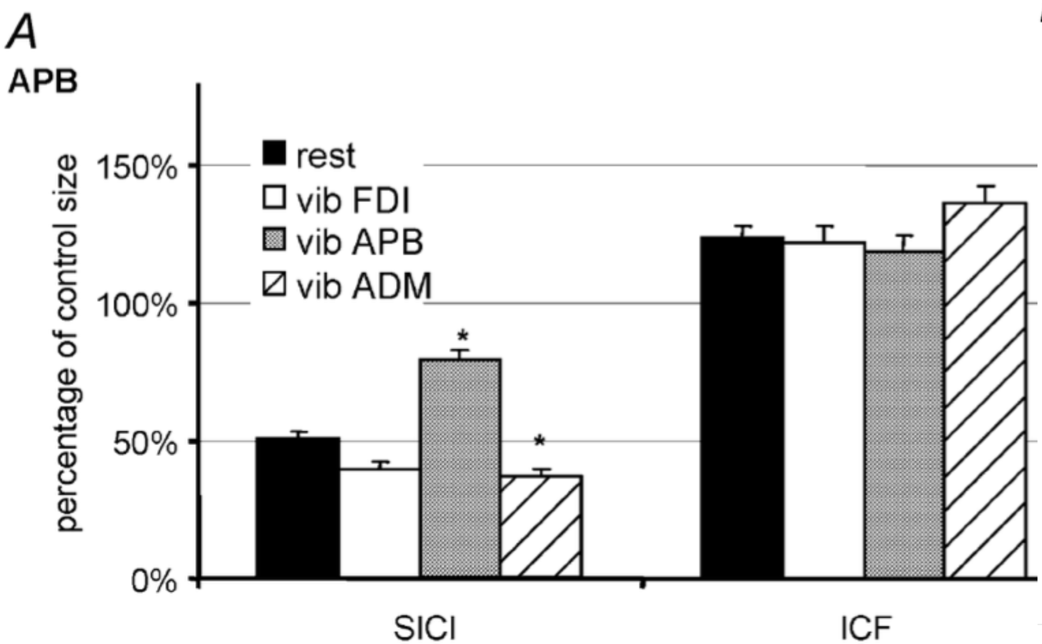
High intensity (Motor)
Low frequency (2Hz)

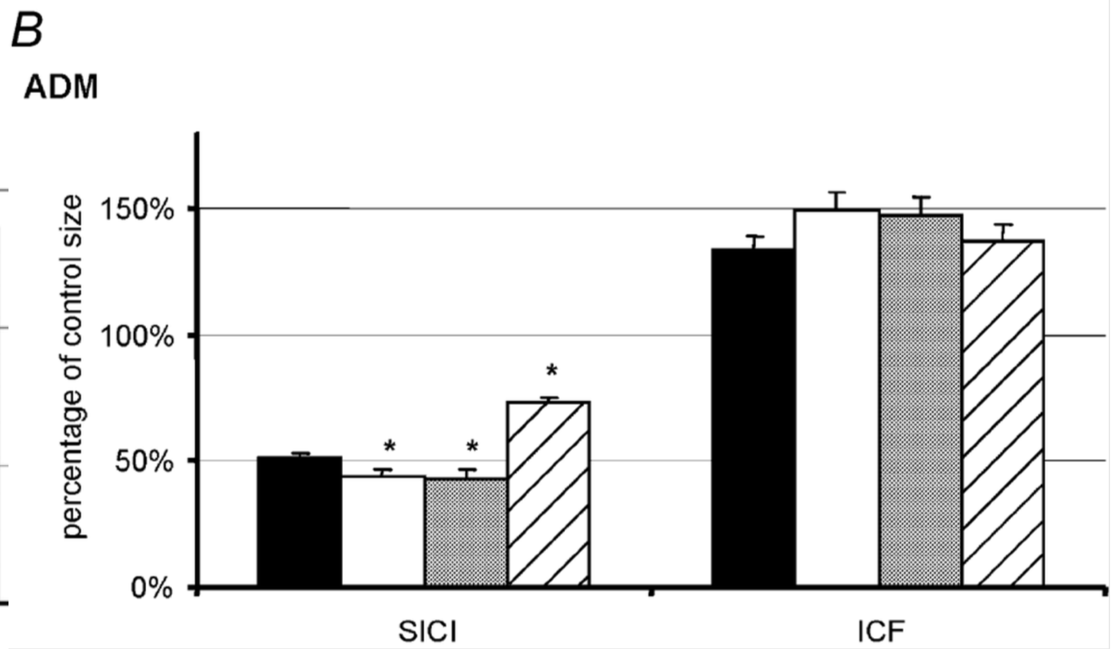
Golaszewski et al. Clin Neurophysiol 2012

No change in M1 excitability

✓ **Stimulus site; due to that stimulus hand were placed out of water**

Vibration stimuli were applied to **APB** Vibration stimuli were applied to **ADM**





Rosencranz et al. J Physiol 2003

Decrease in afferent inhibition (SAI and LAI)

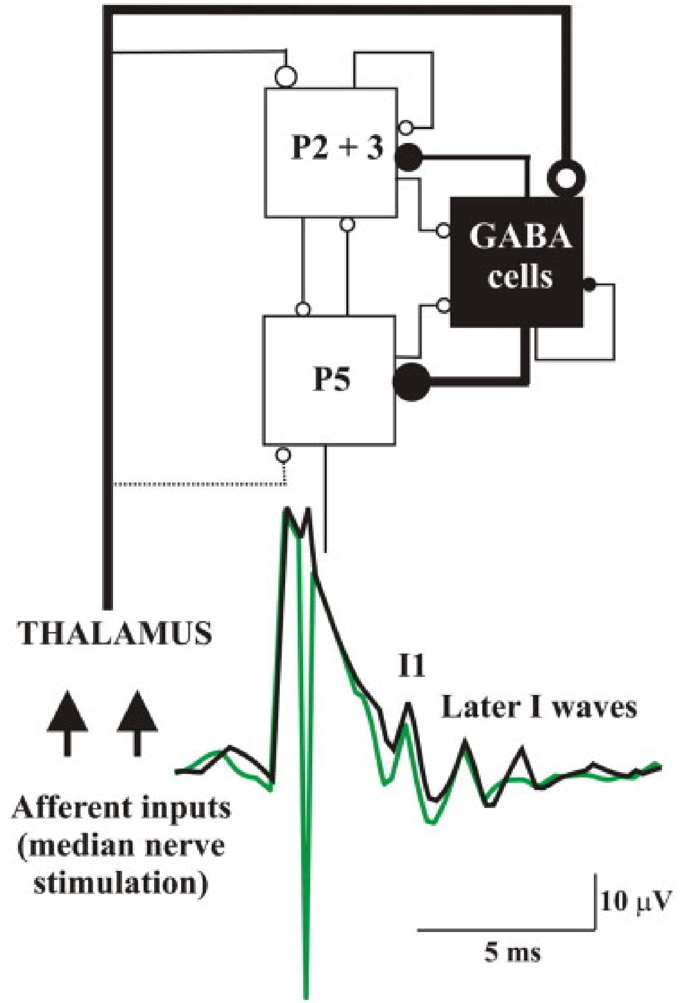
- larger receptive fields induced the activation in wide area of S1

Tambrurin et al. Exp Brain Res 2005

Decreased SAI was due to somatosensory input from wide area of the body

- LAI may result from activation of SI, SII, and the posterior parietal cortex (PPC)?

Chen et al. Exp Brain Res 1999



Di Lazzaro et al. Brain stimulation 2012

Neurophysiological changes during water immersion

during Water immersion *(without change in body temperature)*

- changes sensory cortical excitability
- changes sensorimotor integration
- Is NOT sufficient stimuli to change M1 excitability

Sato et al. Brain Top 2012, BMC neurosci 2012, Clin Neurophysiol 2013

Topics

- **Neurophysiological changes during water immersion**
- **Neural plasticity induced by water immersion**

Neural plasticity induced by water

- Sensorimotor cortex is capable of reorganizing in response to various injures or environmental changes

Sanes et al. Cerebral Cortex 1992, Brasil-Neto et al. Brain 1993

- M1 is reorganized

  - ✓ in association with skill acquisition

    Pascual-Leone et al. Science 1994, J Neurophysiol 1995

  - ✓ By repetition of simple movements

    Classen et al. J Neurophysiol 1997

Cortical plasticity

HEBB's theory   Hebb. The organization of Behaivior 1949

"When an axon of cell A is near enough to excite cell B and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that A's efficiency, as one of the cells firing B, is increased"

Neural plasticity induced by water

- WI is NOT sufficient stimuli to change M1 excitability

Sato et al. Clin Neurophysiol 2013

✓ stimulus intensity and frequency Golaszewski et al. Clin Neurophysiol 2012

✓ modality of afferent input; skin or muscle spindle

Rosenkranz et al. J Physiol 2003

✓ Stimulus site Ridding et al. Exp Brain Res 2005

Neural plasticity induced by water

- Water flow stimulation devise
  - ✓ stimulus intensity (high)
  - ✓ stimulus site (hand)
  - ✓ skin and muscle spindle?

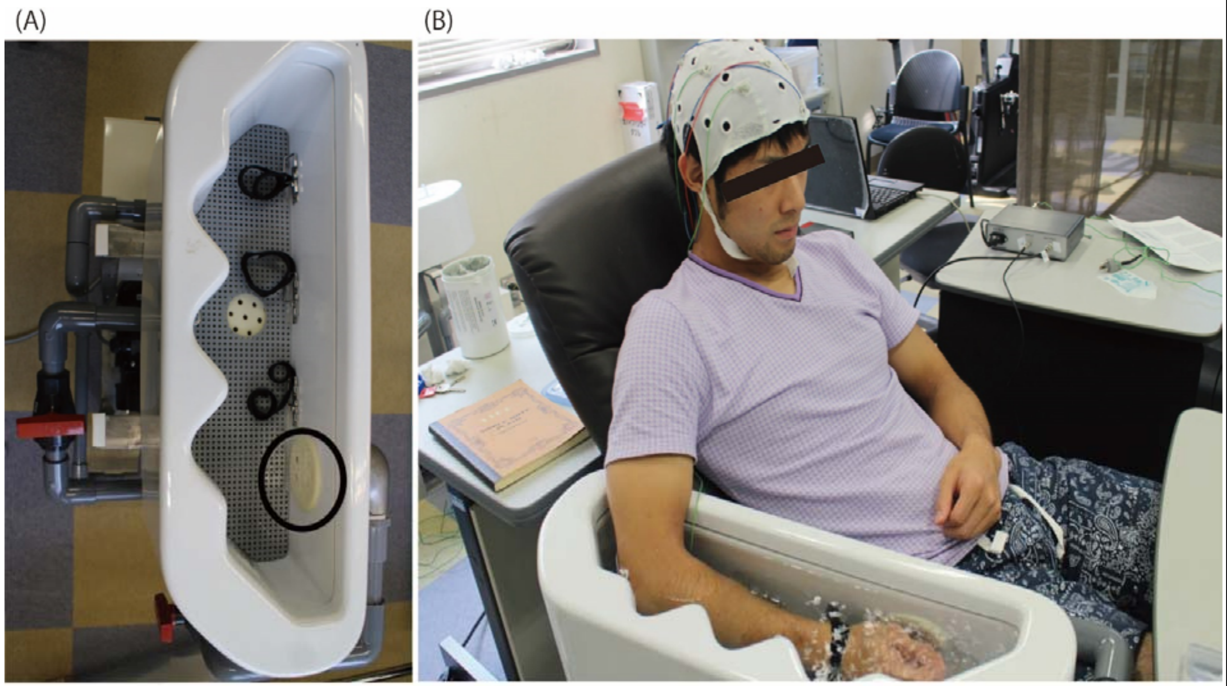
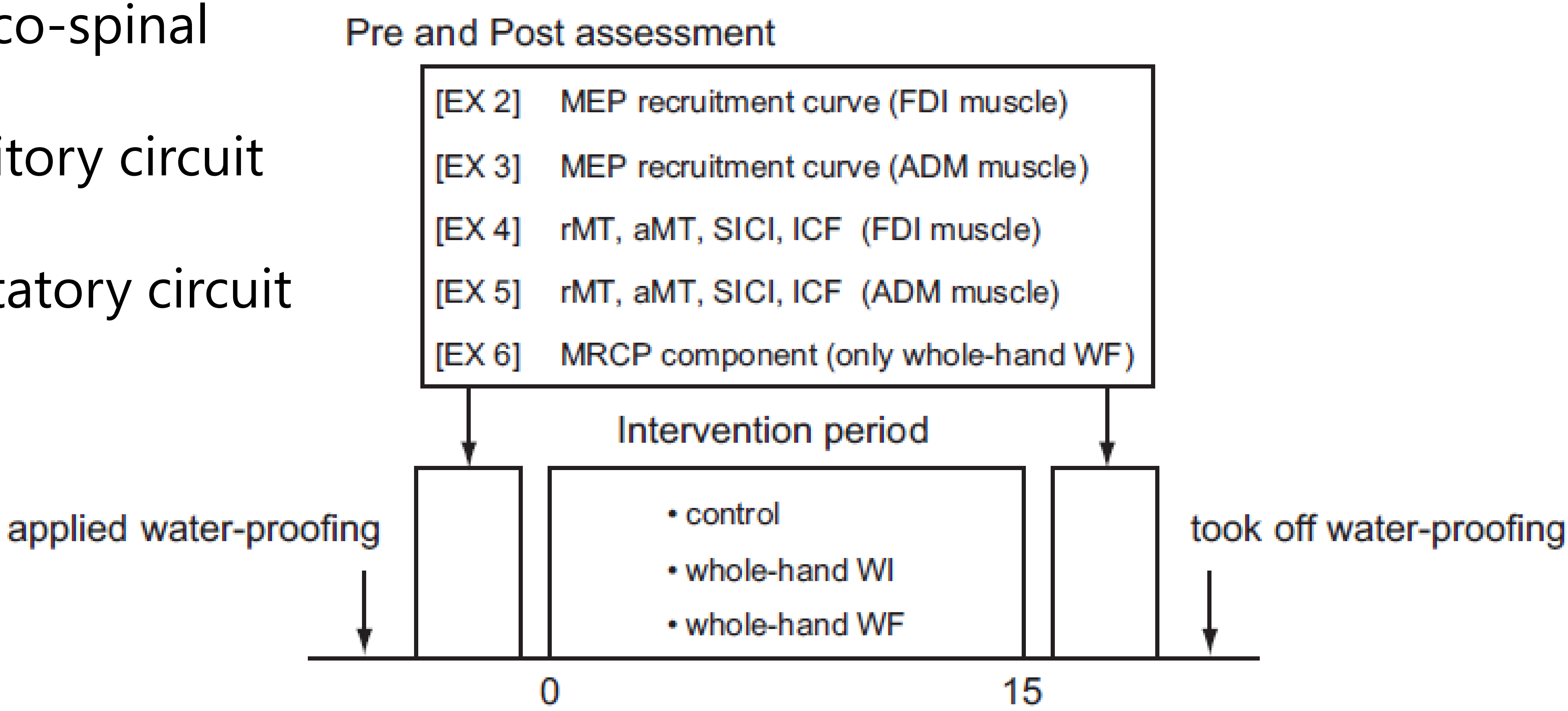


Figure 1. (A) The sluicing device used in this study.
(B) Whole-hand water flow stimulation intervention.
The water jet is within the black circle in (A).

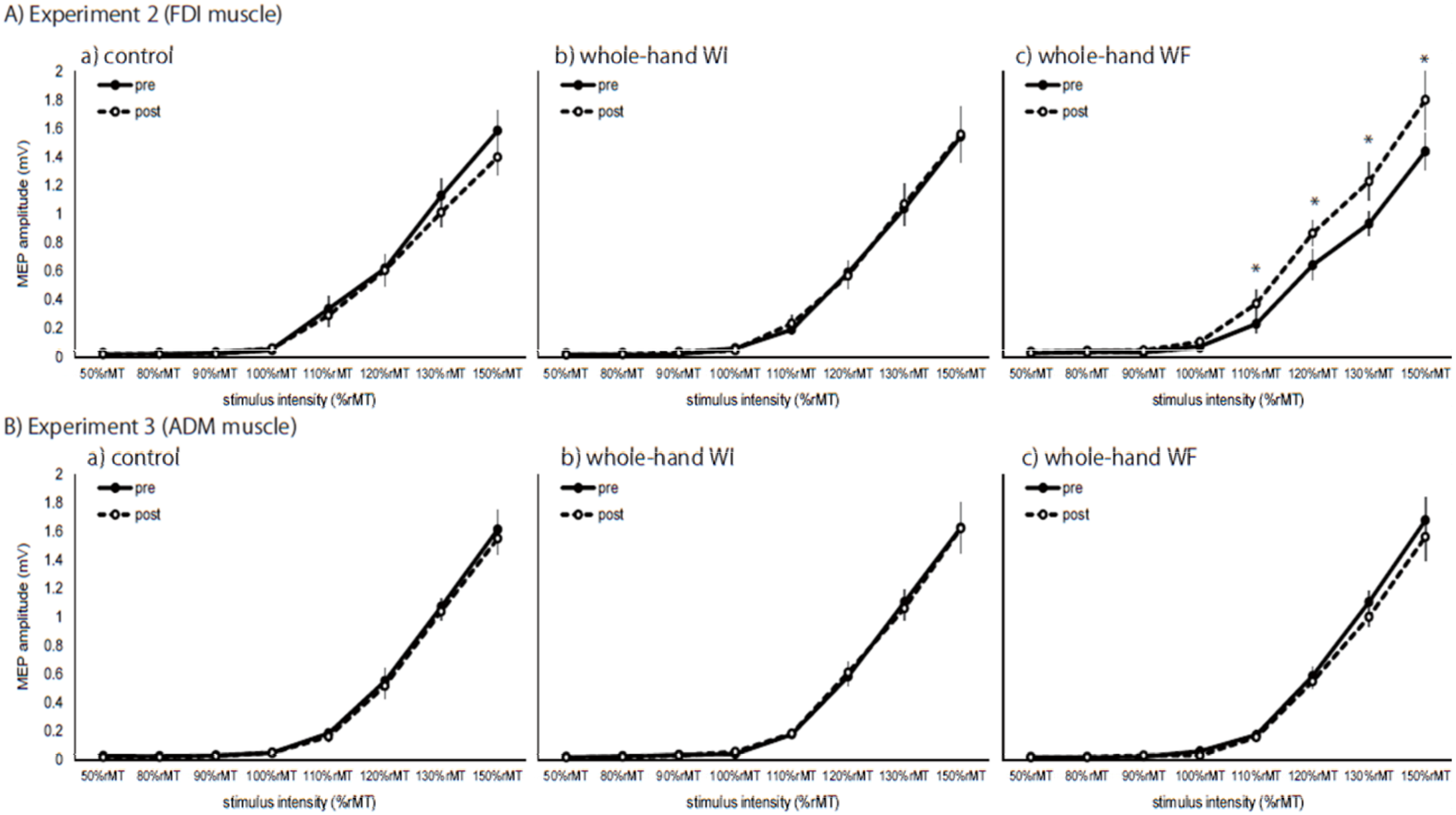
Neural plasticity induced by water

- Cortico-spinal
- Inhibitory circuit
- Facilitatory circuit



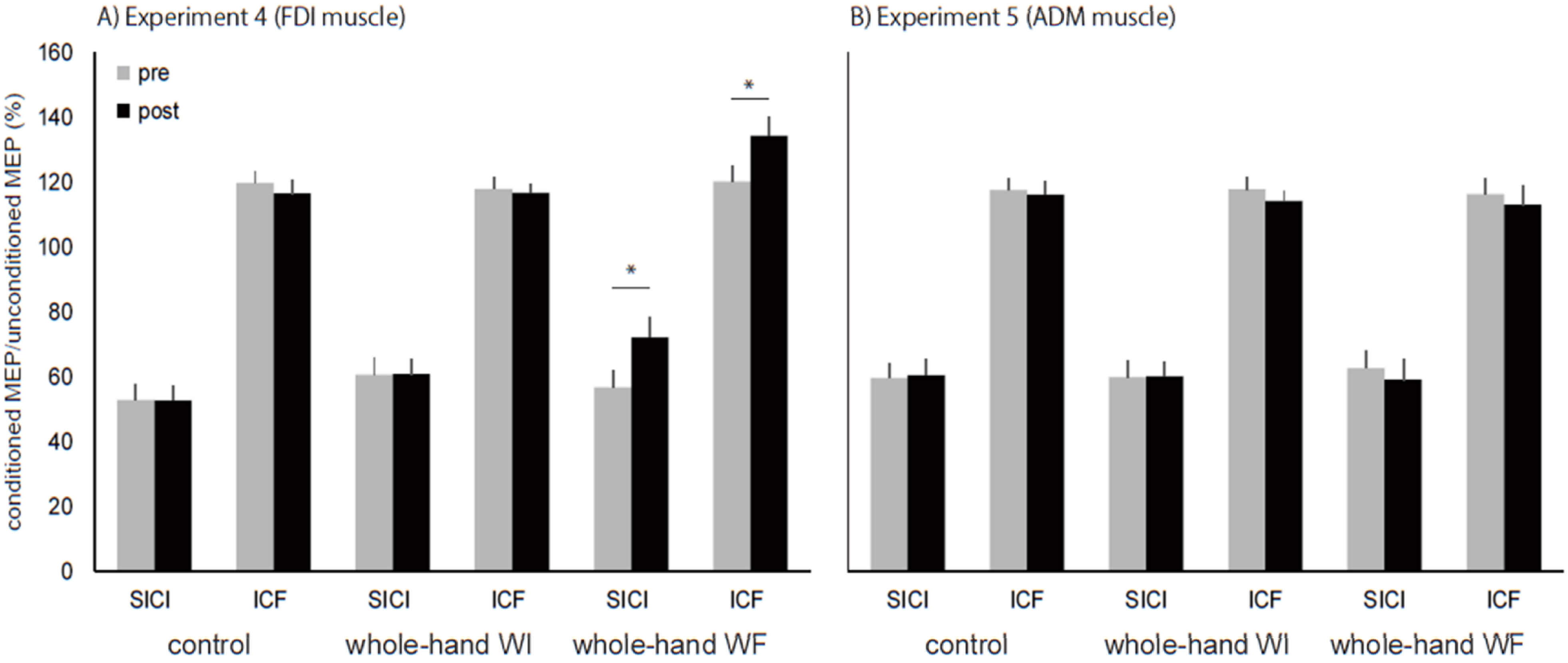
Sato et al. J Neurophysiol 2014

Increased MEP



Sato et al. J Neurophysiol 2014

Decreased SICI and increased ICF



whole-hand WF stimulation could induced neural plasticity in M1

Sato et al. J Neurophysiol 2014

Why was the results different with muscles?

- **Skin and muscle movement in FDI muscle**

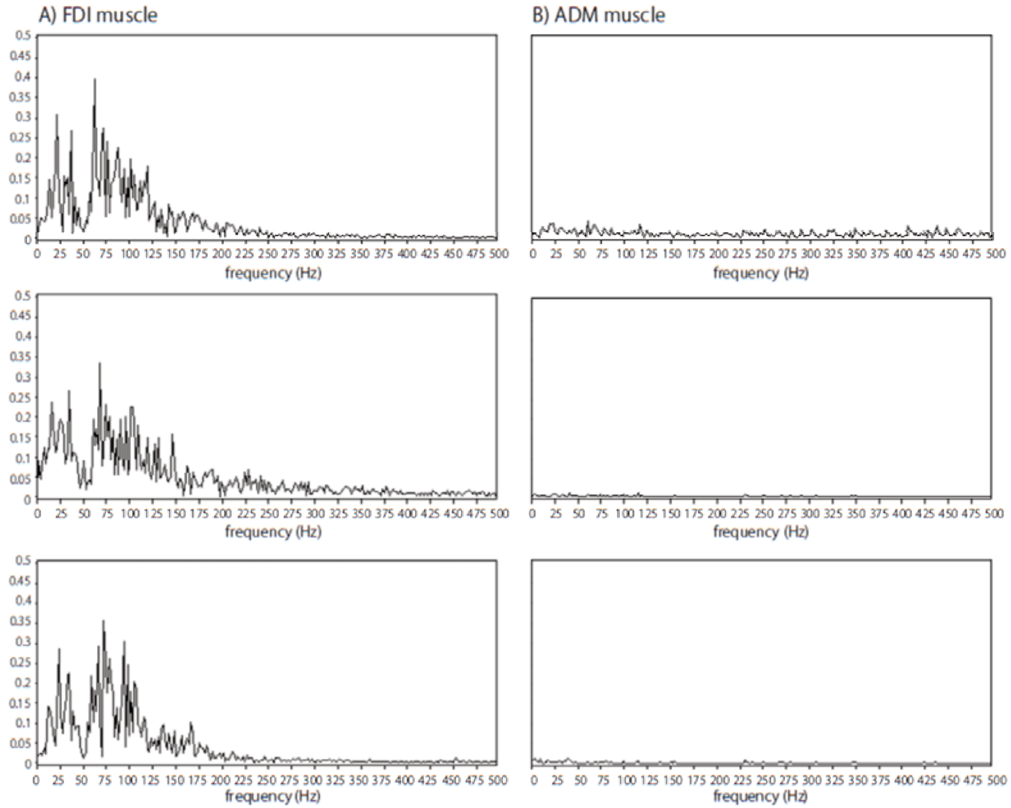


Figure 4. Power spectrum during whole-hand water flow stimulation (WF) in FDI and ADM muscle

the passive movement induced by whole-hand WF stimulation would be important for inducing M1 plasticity.

Sato et al. J Neurophysiol 2014

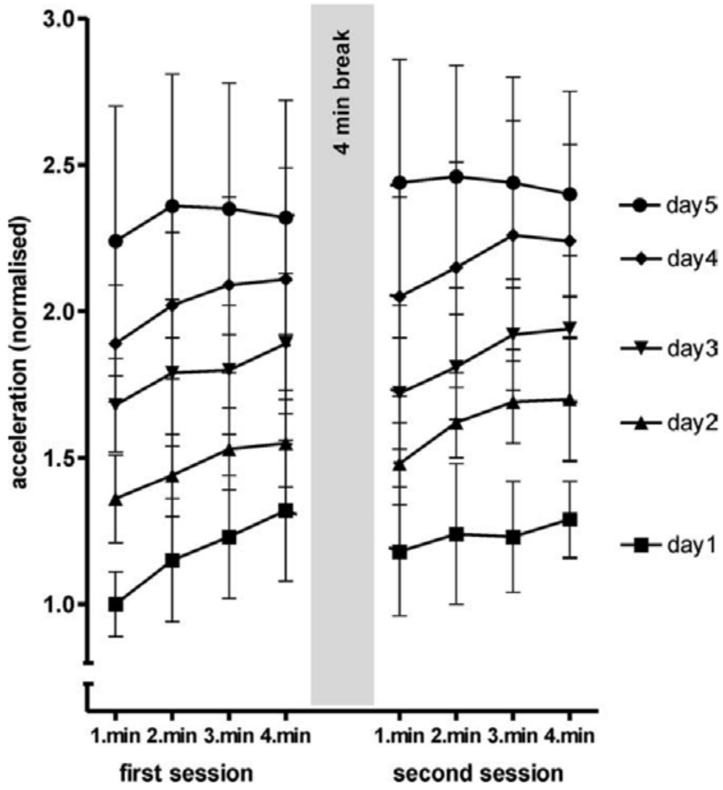
What does it apply for?

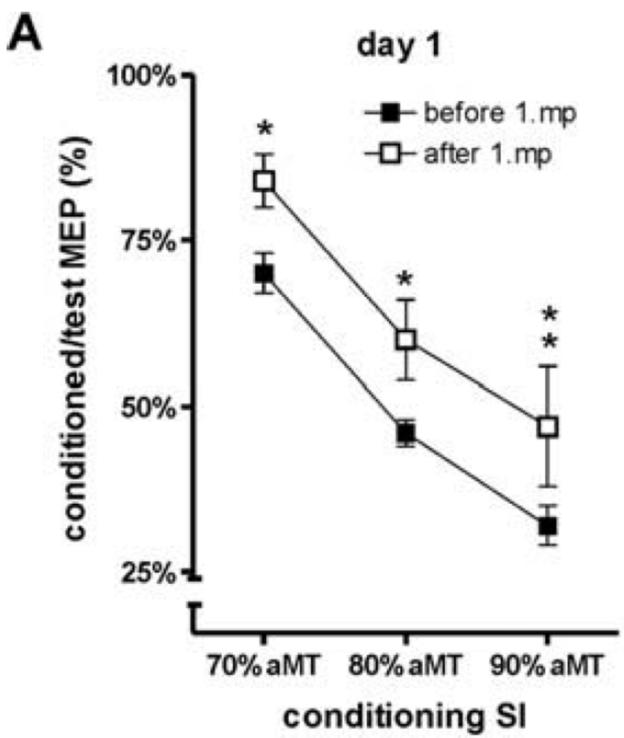
- **Whole-hand WF could induce cortical plasticity in M1**
  - ✓ Higher stimulus intensity
  - ✓ Passive movement in skin and muscle

Motor learning? Rehabilitation?

Motor learning and Rehabilitation

- **SICI significantly decrease as progress of motor learning**



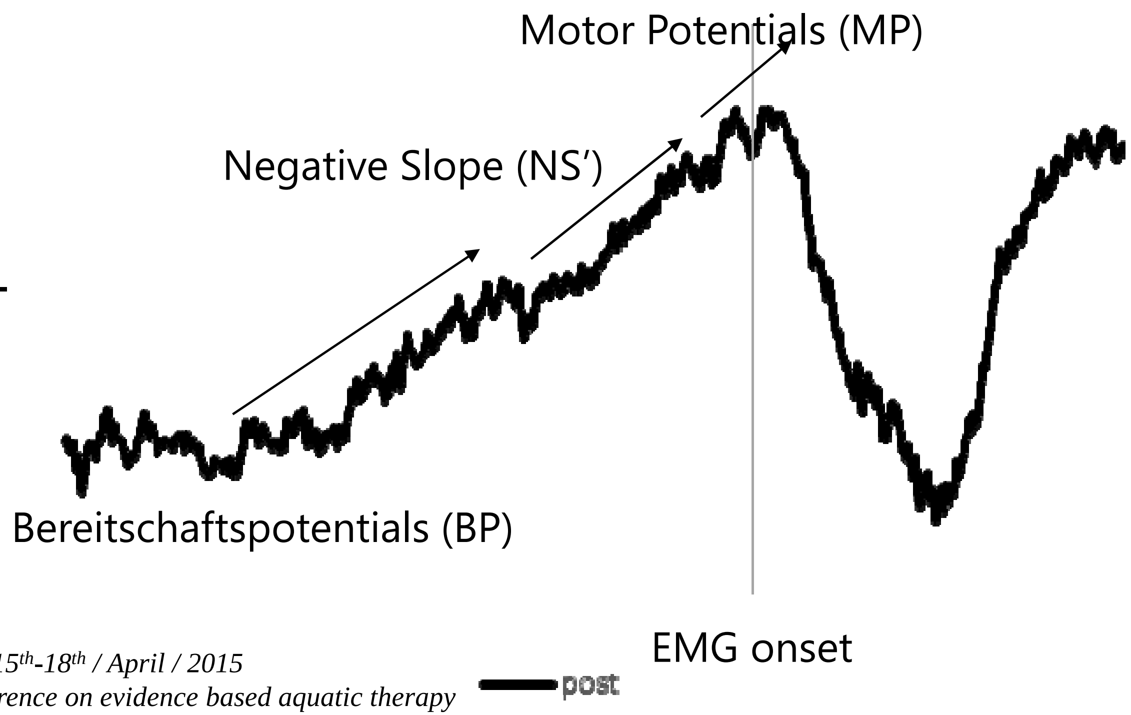


Rosencranz et al. J Neurosci 2007

How about during movement?

- Examine the effects of whole-hand WF on cortical activity during movement using movement related cortical activity (MRCP)

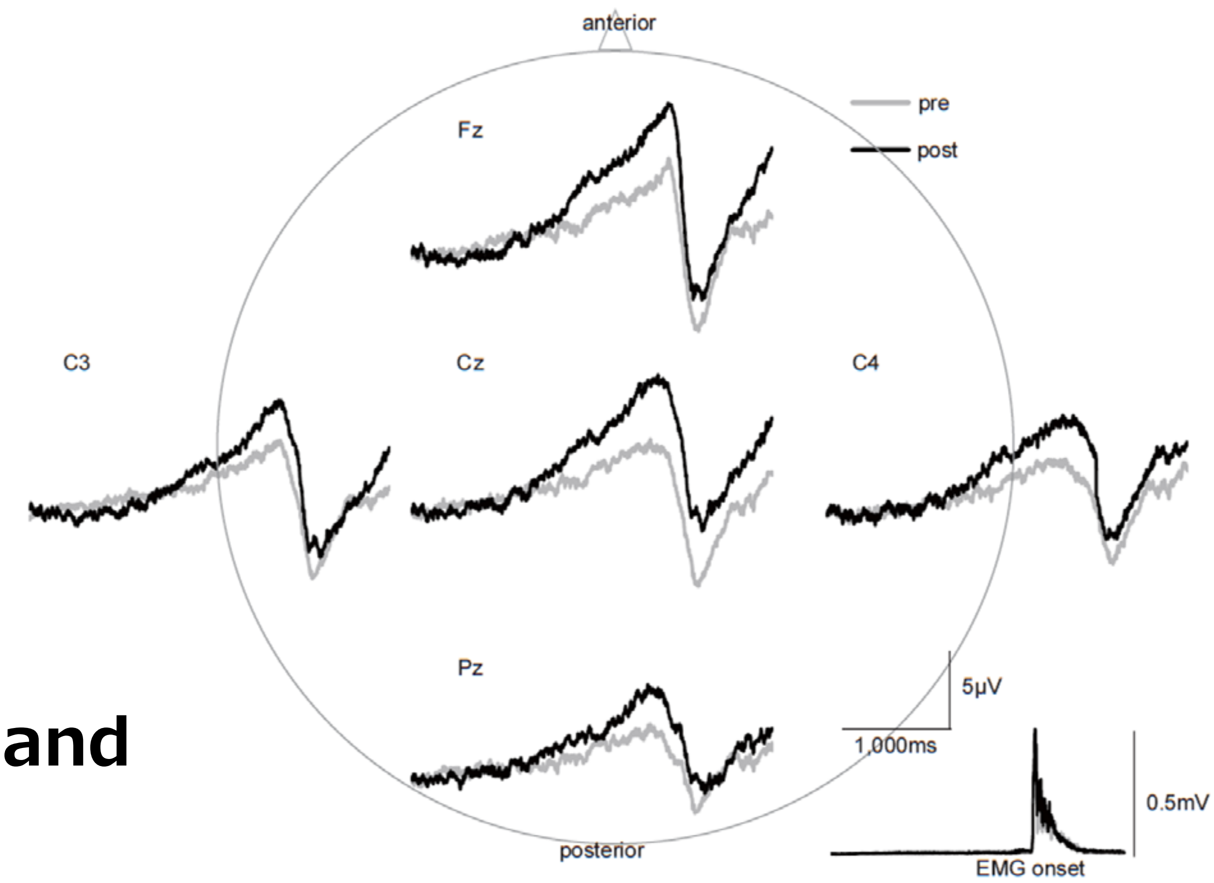
✓ performed brisk abduction movements with their right-hand index finger



Motor learning and Rehabilitation

- **Significant increased BP, NS′ and MP of MRCP**

  Sato et al. J Neurophysiol 2014



- **Good condition for movement due to M1 and SMA activation?**

Conclusion

Neurophysiological changes during Water immersion

- changes **sensory cortical excitability** (BMC neuroscience, 2012)
- changes **sensorimotor integration**
- Is NOT sufficient stimuli to change M1 excitability (Clinical Neurophysiology, 2013)

Neural plasticity by Water immersion

- NOT sufficient stimuli to change M1 excitability
- increase **corticospinal and intracortical excitability**
- would increase **M1 and SMA activation in movement preparation and execution**

(J Neurophysiology 2014, Plos one 2014)