Water immersion modulates sensory and motor cortical excitability

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2nd European conference on evidence based aquatic therapy
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

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<th>baseline</th>
<th>3 months after</th>
<th>6 months after</th>
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<td><strong>Control</strong></td>
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<td><strong>Aquatic</strong></td>
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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


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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°C / axillary level

Blatow et al. Neuroimage 2007
Does WI attenuate short SEP?

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

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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. Electroencephalogr Clin Neurophysiol 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  

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

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

- M1
- Inhibitory circuits
- B (later I-waves)
- D (asynchronous descending activity)
- A (I1-wave)
- C (D-wave)


Stimulation

MEP in FDI muscle

Amplitude
**Intracortical excitability in M1**

- **Paired-pulse paradigm**

- **Motor learning**

- **NIBS plasticity**
  - Murase et al. Brain Stimulation 2015

**MEP induced by single-pulse TMS**

**Short-interval intracortical inhibition (SICI)**

- ISI = 3ms

**Intracortical facilitation (ICF)**

- ISI = 10ms
Sensorimotor integration

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

- **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**
How about primary motor cortex (M1)?

How about primary motor cortex (M1)?

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

No change in M1 excitability

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


- **stimulus intensity and frequency**


- **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

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

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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
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

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 injuries or environmental changes

- M1 is reorganized
  ✓ in association with skill acquisition
  ✓ By repetition of simple movements
    Classen et al. J Neurophysiol 1997
Cortical plasticity

HEBB’s theory

Hebb. The organization of Behavior 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  

  ✓ stimulus intensity and frequency  

  ✓ 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

Pre and Post assessment

- [EX 2] MEP recruitment curve (FDI muscle)
- [EX 3] MEP recruitment curve (ADM muscle)
- [EX 4] rMT, aMT, SICI, ICF (FDI muscle)
- [EX 5] rMT, aMT, SICI, ICF (ADM muscle)
- [EX 6] MRCP component (only whole-hand WF)

Intervention period

- control
- whole-hand WI
- whole-hand WF

applied water-proofing

took off water-proofing

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Increased MEP

A) Experiment 2 (FDI muscle)

B) Experiment 3 (ADM muscle)


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Decreased SICI and increased ICF

whole-hand WF stimulation could induced neural plasticity in M1

Why was the results different with muscles?

- Skin and muscle movement in FDI muscle

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

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
  

- 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]