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Effects of water immersion on short- and long-latency afferent inhibition, short-interval intracortical inhibition, and intracortical facilitation

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HIGHLIGHTS

- We demonstrate that water immersion (WI) modulates sensorimotor integration as indicated by decreased short- and long-latency afferent inhibition.
- WI did not change corticospinal excitability, short-interval intracortical inhibition, or intracortical facilitation.
- A greater understanding of the neurophysiological effects of WI could lead to more efficacious use of aquatic therapy in rehabilitation regimens.

ABSTRACT

Objective: The aim of the present study was to investigate the effect of water immersion (WI) on short- and long-latency afferent inhibition (SAI and LAI), short-interval intracortical inhibition (SICI), and intracortical facilitation (ICF).
Methods: Motor evoked potentials (MEPs) were measured from the first dorsal interosseous (FDI) muscle of fifteen healthy males before, during, and after a 15-min WI at 30 °C up to the axilla. Both SAI and LAI were evaluated by measuring MEPs in response to transcranial magnetic stimulation (TMS) of the left motor cortex following electrical stimulation of the right median nerve (fixed at about three times the sensory threshold) at interstimulus intervals (ISIs) of 20 ms to assess SAI and 200 ms to assess LAI. The paired-pulse TMS paradigm was used to measure SICI and ICF.
Results: Both SAI and LAI were reduced during WI, while SICI and ICF were not significantly different before, during, and after WI.
Conclusions: WI decreased SAI and LAI by modulating the processing of afferent inputs.
Significance: Changes in somatosensory processing and sensorimotor integration may contribute to the therapeutic benefits of WI for chronic pain or movement disorders.
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1. Introduction

Water immersion (WI) activates several distinct somatosensory modalities, including tactile, pressure, and thermal sensations. Somatosensory inputs received during WI can induce a variety of cardiovascular and respiratory responses, including decreased heart rate (Marabotti et al., 2009), increased stroke volume caused by increasing venous return (Christie et al., 1990), and reduced functional residual capacity (Farhi and Linnarsson, 1977; Leddy et al., 2001). These physiological responses can have therapeutic benefits; indeed, WI is part of rehabilitation regimes for orthopedic, cardiovascular, and respiratory disorders. WI once a week also improves the activities of daily living (ADL) in frail elderly and hemiplegic patients after stroke (Sato et al., 2007). Benefits to neurological patients suggest that WI may influence cerebrocortical processing; however, this remains to be determined. Elucidating the cortical sensorimotor processes induced or modulated by WI and the effects of WI on the excitability of the motor cortex will help delineate the mechanisms of sensorimotor integration and could facilitate the development of improved aquatic therapies for neurological patients.

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Transcranial magnetic stimulation (TMS) is a noninvasive technique useful for the functional evaluation of the circuits of the human cerebral cortex (Hallett, 2000). Paired-pulse TMS of the motor cortex and pairing of single TMS pulses with peripheral electrical nerve stimuli at specific interstimulus intervals (ISIs) can recruit distinct inhibitory circuits in the motor cortex (Di Lazzaro et al., 2004) and thereby modulate sensorimotor integration and motor output. Two TMS responses indicative of the activation of inhibitory circuits in the motor cortex are short- and long-latency afferent inhibition (SAI and LAI). Motor evoked potentials (MEPs) in hand muscles elicited by TMS of the motor cortex can be attenuated by conditioning electrical stimuli (ES) of the contralateral median nerve evoked about 20 ms (for SAI) or 200 ms (for LAI) before TMS (Chen et al., 1999; Tokimura et al., 2000). Both SAI and LAI result from corticocortical inhibitory transmission originating in the somatosensory cortex (Chen et al., 1999; Tokimura et al., 2000). Several studies have shown that SAI is pathway specific in that local sensory inputs induce greater MEP decreases in nearby muscles (Classen et al., 2000; Tamburin et al., 2001). However, Tamburin et al. (2005) also demonstrated weaker SAI for more widespread sensory inputs, possibly due to afferent convergence. Paired-pulse TMS can measure short-interval intracortical inhibition (SICI) and intracortical facilitation (ICF) (Kujirai et al., 1993; Ziemann et al., 1996) depending on ISI. There is strong evidence that SICI and ICF originate in the motor cortex (Di Lazzaro et al., 1998, 2000, 2006). Several studies have found that a focused afferent input can influence SICI and ICF only in local muscles (Rosenkranz et al., 2003; Rosenkranz and Rothwell, 2003, 2004).

Sensorimotor integration is the process by which the motor system continuously processes sensory information to prepare for motor tasks and to improve the execution of fine motor activities (Evarts and Fromm, 1977; Rosen and Asanuma, 1972). Sensorimotor integration has been studied in animal models using microstimulation (Cheney and Fetz, 1984; Rosen and Asanuma, 1972) and in the intact human cortex using TMS. In a previous study, we found that water immersion attenuated the amplitude of somatosensory evoked potentials (SEPs) induced by median nerve stimuli (Sato et al., 2012b). These results suggested that WI influences the somatosensory processing of other sensory inputs. In addition, our previous study using functional near infrared spectroscopy (fNIRS) found that WI influenced activity throughout the sensorimotor cortex, including the primary somatosensory area (SI), posterior parietal cortex (PPC), primary motor area (MI), and supplementary motor area (SMA) (Sato et al., 2012a). In light of these results, we suggest that WI may also influence sensorimotor integration; however, there is no direct experimental evidence for this. In the present study, we examined sensorimotor integration and modulation of intracortical neuronal circuits in the hand area of the motor cortex during WI.

Based on our previous results that WI enhanced SEP gating (Sato et al., 2012b) and increased the activities of the sensorimotor region (Sato et al., 2012a), we hypothesized that WI of most of the body would substantially change SAI and LAI. Additionally, sensory inputs changed SICI and ICF (Golaszewski et al., 2012; Rosenkranz and Rothwell, 2004), suggesting that WI may also modulate intracortical circuits. However, since SICI and ICF show great topographic specificity for the afferent input (Rosenkranz and Rothwell, 2003), we speculated that they would not be changed by WI when the hand was not actually in the water.

2. Methods

2.1. Subjects

We examined 15 healthy male volunteers between 19 and 26 years of age (mean age, 21.7 ± 0.4 years) after obtained their informed consent. All subjects were right-handed, none had a history of neurological or psychiatric disease, and none were taking any medications. The present study was conducted in accordance with the Declaration of Helsinki and approved by the local ethical committee.

2.2. Electromyography (EMG) recording

EMG recordings were obtained using surface electrodes placed over the right first dorsal interosseous (FDI) muscle using 9-mm-diameter disposable adhesive silver/silver-chloride surface electrodes. The active electrode was placed over the muscle belly and the reference over the interphalangeal joint of the index finger. Signals were amplified and filtered (gain $\times$ 1000, 5 Hz–1 kHz; AB-601G Nihon Kohden, Japan) and then transferred via a micro 1401 laboratory interface (CED Cambridge, UK) to a personal computer for further analysis.

2.3. Transcranial magnetic stimulation (TMS)

TMS was performed using two MAGSTIM 200 stimulators connected by a Y-cable to a figure 8 coil with an external wing diameter of 9 cm (Magstim, Dyfed, UK). The coil was held with the handle pointing backwards and laterally at approximately 45° to the sagittal plane and was optimally positioned to obtain MEPs in the target muscle. The coil position was marked on the skull to allow the experimenter to reposition the coil in the same spot before each measurement and consistency of the coil position was continuously monitored during the experiment. With this coil orientation, the induced current in the brain would flow in a posterior to anterior direction.

Resting motor threshold (RMT) was defined as TMS intensity needed to elicit MEPs of at least 50 μV or more in at least 3 of 6 successive trials in the relaxed target muscle (Maruyama et al., 2006). For the active motor threshold (AMT), a minimum MEP of 200 μV was necessary in 50% of all trials in activated (5% of maximum voluntary contraction) muscle (Ridding et al., 1995). The subjects viewed the EMG activity as visual feedback to assist in complete relaxation or to maintain a constant level of background activity.

2.4. SAI and LAI

SAI was studied by pairing TMS (Test Stimulation, TS) and median nerve (afferent) stimulation (Conditioning Stimulation, CS) with a 20-ms ISI (Chen et al., 1999; Di Lazzaro et al., 2005, 2007; Tokimura et al., 2000). LAI was examined using the same method (Chen et al., 1999) but with a 200-ms ISI. Conditioning stimuli were single electrical pulses (200 μs) applied through bipolar electrodes to the right median nerve at the wrist (cathode proximal) before TS. The intensity of CS was set at about three times the sensory threshold. The intensity of TS was adjusted to evoke an EMG response in the relaxed FDI muscle of approximately 1 mV peak-to-peak.

2.5. SICI and ICF

SICI and ICF were studied using the technique of Kujirai et al. (1993) and Ziemann et al. (1996). Two TMS pulses were administered through the same stimulating coil over the left motor cortex and the effect of the first (conditioning) stimulation on the second (test) stimulation was measured. CS was set at an intensity of 80% AMT. The intensity of TS was adjusted to elicit an unconditioned test MEP in the relaxed right FDI muscle of approximately 1 mV peak-to-peak amplitude. The following ISIs were selected: 3 and 10 ms.

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