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Dynamic modulation of corticospinal excitability and short-latency afferent inhibition during onset and maintenance phase of selective finger movement

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HIGHLIGHTS

- Motor surround inhibition was present only at the onset phase, but not at the maintenance phase of movement.
- Short-latency afferent inhibition (SAI) was decreased at onset, but not for the maintenance phase of selective movement in both active and surrounding muscles.
- SAI does not contribute either to initiation phase or to maintenance phase of selective movement.

ABSTRACT

Objective: During highly selective finger movement, corticospinal excitability is reduced in surrounding muscles at the onset of movement but this phenomenon has not been demonstrated during maintenance of movement. Sensorimotor integration may play an important role in selective movement. We sought to investigate how corticospinal excitability and short-latency afferent inhibition changes in active and surrounding muscles during onset and maintenance of selective finger movement.
Methods: Using transcranial magnetic stimulation (TMS) and paired peripheral stimulation, input-output recruitment curve and short-latency afferent inhibition (SAI) were measured in the first dorsal interosseus and abductor digiti minimi muscles during selective index finger flexion.
Results: Motor surround inhibition was present only at the onset phase, but not at the maintenance phase of movement. SAI was reduced at onset but not at the maintenance phase of movement in both active and surrounding muscles.
Conclusions: Our study showed dynamic changes in corticospinal excitability and sensorimotor modulation for active and surrounding muscles in different movement states. SAI does not appear to contribute to motor surround inhibition at the movement onset phase. Also, there seems to be different inhibitory circuit(s) other than SAI for the movement maintenance phase in order to delineate the motor output selectively when corticospinal excitability is increased in both active and surrounding muscles.
Significance: This study enhances our knowledge of dynamic changes in corticospinal excitability and sensorimotor interaction in different movement states to understand normal and disordered movements.

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1. Introduction

Ability to make highly selective finger movements is a unique feature of human motor control. It is believed that the human motor system has a physiological mechanism to suppress unwanted movements and release only desired movements: this phenomenon is called "motor surround inhibition (mSI)" (Sohn and Hallett, 2004). Several studies demonstrated mSI at the onset of movement or phasic movement, but not during maintenance of muscle contraction or tonic movement. One study showed that there was surround facilitation rather than inhibition for the maintenance phase of movement (Beck et al., 2008).

The exact mechanism of mSI is still unknown. It is possible that sensorimotor interaction also plays a role in selective movement. For example, the somatosensory evoked potential is selectively attenuated for the particular body part that is engaged in the movement at the onset as well as during maintenance of contraction (Rushton et al., 1981; Tapia et al., 1987). Sensorimotor integration can be also assessed by transcranial magnetic stimulation (TMS). The motor evoked potential (MEP) amplitude is substantially reduced when preceded by peripheral nerve stimulation at a short latency (~20 ms), an effect known as short-latency afferent inhibition (SAI) (Tokimura et al., 2000). A previous study showed that SAI was reduced in the active hand muscle during both the onset and maintenance phases of movement (Asmussen et al., 2013), but SAI in surrounding muscle at the onset phase showed contradictory results (Voller et al., 2006; Richardson et al., 2008). SAI in the surrounding muscle during the maintenance movement phase has never been tested.

It is crucial to learn the whole scope of dynamic changes in corticospinal excitability and sensorimotor interaction in the different movement states to understand normal and disordered movements. Therefore, we have addressed two questions in this study: How does corticospinal excitability change in active and surrounding muscles for different movement states? Based on results from previous studies (Beck et al., 2008), we expected that there would be surround inhibition only for onset phase and not for maintenance phase. Our second question was how SAI was modulated in active and surrounding muscles for different movement states. We speculated that SAI would be enhanced in the surrounding muscle for the maintenance phase compared to active muscle to counteract increased corticospinal excitability.

2. Methods

2.1. Experiment

2.1.1. Subjects

Thirteen healthy right-handed individuals (7 males, 6 females, age 33.92 ± 8.67) participated in this study. All subjects were at least 18 years of age, right-handed, with no history of neurological or psychiatric disorders and were not taking any medications. They all were normal on neurological examination done within the past year. All participants provided written, informed consent before the experiments. The protocol was approved by the Combined Neurosciences – Institutional Review Board of the National Institutes of Health, USA.

2.1.2. Recording

The subjects were seated in a comfortable chair and their right hand was placed on the table, which was adjusted to their comfort level. Disposable surface Ag–AgCl electrodes were placed on the right abductor digiti minimi (ADM) and first dorsal interosseus (FDI) muscles in a belly-tendon montage. The EMG signal was amplified and band-pass filtered (10–2000 Hz) using a conventional EMG machine (Nihon Kohden). The signal was digitized at 5 kHz with Signal software version 5.09 (Cambridge Electronic Design, Cambridge, UK) and stored in a computer for off-line analysis. Individual MEPs were measured during three phases of movement (rest, onset, and maintenance).

2.1.3. Motor task

All tests were performed at rest or during different phases of a selective movement of the right index finger activating FDI as a synergist while keeping other muscles relaxed. With their right palm flat on a table in front of them, subjects were instructed to push down on a small force transducer (Strain Measurement Devices; model S215 load cell) to produce 10% of their maximum force (10% F_{max}). EMG activity corresponding to 10% F_{max} was marked on the EMG screen for visual feedback. Then, the force transducer was removed and they were instructed to press on the table to match the EMG activity of 10% F_{max} at the tone and maintain the same force for the duration of the tone (3 s) (Fig. 1). The tone was repeated every 7 s with 15% variation. The reason for not using the force transducer for the main experiment was to keep the subject's hand relaxed as much as possible in the same position while recording different movement states. Muscle activities of FDI and ADM were monitored on a continuous EMG screen to ensure that only the target muscle was activated.

2.1.4. TMS

TMS was performed with a figure-of-eight-shaped coil (7-cm diameter for each half) connected to a Magstim 200 magnetic stimulator (Magstim, Whitland, Dyfed, UK) that delivers monophasic pulses. The coil was positioned tangentially on the scalp over M1 at an angle of 45° to the midline with the handle pointing backwards to induce a current in the postero-anterior direction in the brain. The optimal site for evoking maximal amplitude MEPs from the ADM was identified as the hot spot. TMS over the ADM hot spot was used to simultaneously measure corticospinal output to the ADM and FDI.

2.1.5. Paired pulse experiment with peripheral stimulation

Ring electrodes were put in the right 2nd and 5th fingers around proximal and distal interphalangeal joints and electrical stimulation was given through Digitimer (Stimulator model DS7A, Hertfordshire, England) using a pulse duration of 200 μs. Sensory threshold was measured for the 2nd and 5th fingers and 300% of the perceptual threshold of each finger was used for digital stimulation for paired stimulation (Tokimura et al., 2000). The peripheral stimulation was given 25 ms prior to the TMS pulse for each movement state to elicit SAI. The fixed interval of 25 ms was frequently used in previous studies for SAI (Asmussen et al., 2013).

2.1.6. Experimental design

MEPs were measured at three different phases of the movement: rest, onset (at the onset of EMG >100 μV in FDI), and maintenance (2 s after the onset of the movement) (Fig. 1). For each movement state, input-output recruitment curve (IOC) was obtained and the data were fitted to the Boltzmann sigmoidal function (see below, outcome measures). For IOC, 60 single pulses were given; 3 pulses for each 5% increment from 5% to 100% maximum stimulation output. Then the corresponding S50 (stimulation intensity required to obtain a response of 50% of the maximum) for FDI and ADM were used as test stimulus (TS) intensities for SAI measurements for the muscle and movement state that was tested. Six blocks of SAI were recorded for each movement state (rest, onset and maintenance) and muscle (ADM and FDI). Thirty pulses were given in one SAI block; TMS with 2nd digit stimulation, TMS with 5th digit stimulation and TMS only. The subject