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# Inhibitory Interference to Abandonment of Voluntary Finger Movement by Single-pulse Transcranial Magnetic Stimulation

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*Abstract*— **Brain function dynamics related to an inhibitory interference in voluntary motor abandonment was investigated with single-pulse transcranial magnetic stimulation (TMS) and electroencephalogram (EEG). As the voluntary motor movement, a point-to-point reaching movement of the right index-finger was conducted. The starting time of the movement was indicated with the clock making one revolution for 4 s. The time the clock hand passed the 9 o'clock position was defined as a go-signal. In the go trials, the subject was instructed to start the movement at the timing of the go signal. In some trials, called as pre-stop trials, a stop signal was presented with red LED illumination -100 ms from the timing of the go-signal. The go-trials and pre-stop trials were randomly performed in the series of the trials. In all trials, TMS or sham-TMS were conducted. TMS was delivered with a round coil on the subject's head at various timings. Sham-TMS trials were with a click sound of TMS produced by another coil located near the head without the brain stimulation. In the sham-TMS trials of the pre-stop trials, the subject was able to prevent the finger movement. However, the TMS conducted at -150, -100 or -50 ms from the go-signal induced the involuntary finger movement in the pre-stop trials. We also measured brain potentials in the sham-TMS and TMS trials. The potential at Fz electrode showed a large positive peak in the sham-TMS trials of the pre-stop trials, whereas the potentials at the same latency were attenuated in the TMS trials of the pre-stop trials. These results indicated that the single-pulse TMS applied around the stop-signal in the reaching finger movement could intervene in the brain function of the voluntary motor abandonment conducted at medial frontal cortex.**

## I. Introduction

It is well known that the motor readiness potential (Bereitschaftspotential, BP) was observed in voluntary movements [1-4]. Libet *et al.* demonstrated that the BP, which shows gradual negative shift, began around 800 ms prior to motor activity observed in electromyography (EMG) in the voluntary finger movement [2]. This initial component of BP is supposed to originate from the activity of supplementary motor area (SMA), pre-SMA and premotor area (PM) [3,4] To achieve flexible movement adapted to unexpected occasions, the motor intention must be changed or abandoned on the way of the motor preparation prior to the movement initiation. In our previous study [5], finger pushing of a force sensor was carried out. In the series of the trials, the subject was able to abandon the motor intention with a stop-signal presented at 100 ms before the go-signal. The abandonment of the motor intention with the stop-signal induced the large positive potential, which was not observed in the go task, at front-central scalp at 300ms after the stop-signal. This result suggests that the observed positive component originated from the cortical activity concerning the abandonment of the motor intention. If some brain stimulation can intervene in the cortical motor process, the dynamic brain function in motor control can be revealed with the observation of the motor response to the intervention. In the present study, we tried to intervene in the cortical motor process by single-pulse transcranial magnetic stimulation (TMS). The TMS was conducted in the task of abandonment of voluntary finger intention with a stop signal at -100 ms from the go-signal as in our previous study [5]. The Motor response was analyzed with the observation of the finger trajectory. Furthermore, the change of the brain potential, which was observed specifically in the abandonment of the motor intention, with TMS was investigated.

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## II. Method

All of the experiments were performed under appropriate conditions in accordance with the Declaration of Helsinki. The subjects gave informed consent.

The experimental setup is shown in Fig. 1. The subject sat on a medical chair with a head-rest to immobilize the head. The subject put his both arms on the table. The point-to-point finger reaching task was conducted. The index finger of the right hand on the wooden block was moved downward from the extended position to the flexed position in the vertical

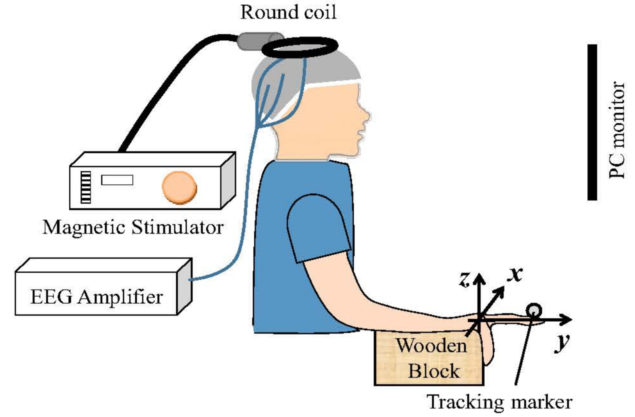



Figure 1. Experimental setup

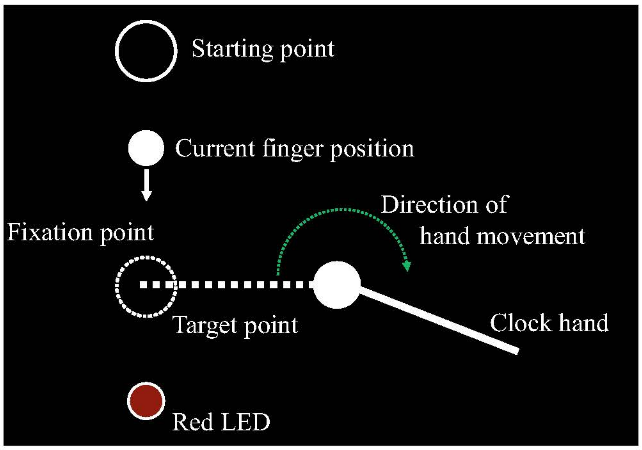
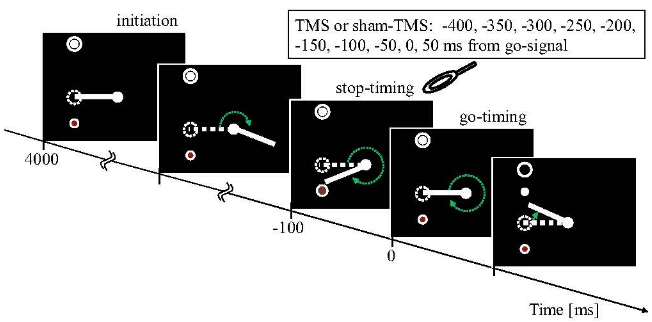
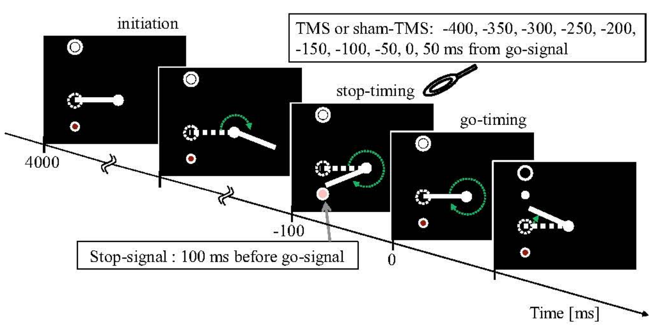



Figure 2. PC monitor indcating the finger position associated with the starting and target points and the clock.




(a) Go trial with TMS or sham-TMS




(b) Pre-stop trial with TMS or sham-TMS

Figure 3. Experimtntal protcols.

direction which was defined as z-axis. The only metacarpophalangeal (MCP) joint of the index finger was allowed to move with fixation of other two joints of the finger. The z-coordinates of the starting position and the target position were set at 0 mm and 100mm respectively. The position of the finger-tip of right index finger was tracked by a motion-capture system (VICON T10, Vicon Motion Systems, U.K.) with a sampling frequency of 200 Hz. The measured z-coordinate of the finger-tip was indicated on the PC monitor associated with the z-coordinates of the starting and target points as shown in Fig. 2. The clock revolving once every 4 s was shown on the PC monitor to notify the starting time of the movement. The subject started to move the finger at the moment the clock-hand passed the 9 o'clock position, which was adopted as a go-signal. The target point overlapped on the 9 o'clock position of the clock was defined as a fixation point as shown in Fig. 2. A red LED was attached at 5 mm below the fixation point to indicate a stop-signal. In the trials with the stop-signal, hereinafter referred to as "pre-stop trials", the red LED was presented at 100 ms before the go-signal so as to abandon the motor intention. The subject performed a randomized series of trials composed with go-trials and pre-stop trials. In the series of trials, TMS was applied with a round coil located horizontally on the scalp. The TMS stimulator used in the experiment was a Magstim model 2000 magnetic stimulator. The stimulator produced monophasic magnetic pulse which induced electric field in the head clockwise in view of the above. The intensity of the TMS was set at 85 % of the resting motor threshold of the first dorsal interosseous (FDI) muscle of the right hand. The TMS was randomly conducted at -400, -350, -300, -250, -200, -150, -100, -50, 0 or 50 ms from the go-signal in both go trials and pre-stop trials. To evaluate the effect of the TMS, the sham-TMS, which made a click sound with another coil located near the head without brain stimulation, was also conducted in the series of trials.

The brain activity altered with the TMS in the abandonment of the motor intention was measured with the

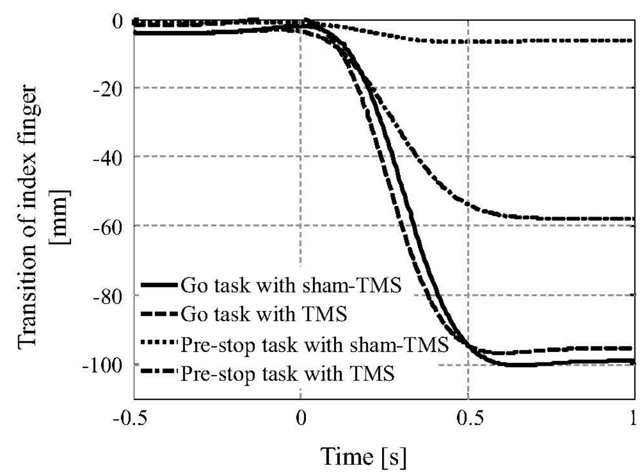



Figure 4. The transitions of the averaged point-to-point reaching movements. The abscissa indicates the time with the go-signal as 0 s.

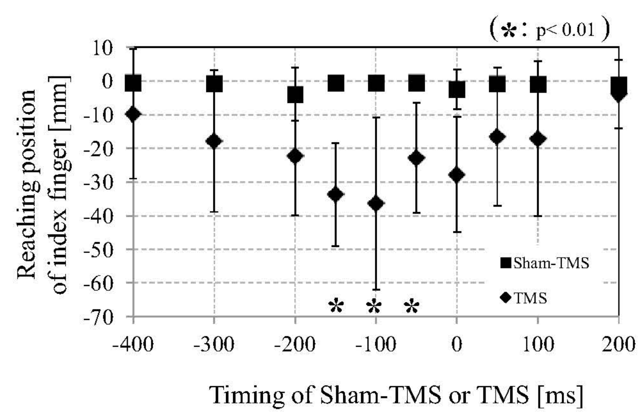



Figure 5. Reaching positions of the index finger-tip in the pre-stop trials with TMS and sham-TMS.

electroencephalogram (EEG). The TMS or sham-TMS was conducted at -150 ms from the go-signal in the series of go and pre-stop trials. The EEG was recorded at 16 surface electrodes (g.BUTTERFLY Au active electrodes, g.tec medical engineering, Austria) mounted on a cap (g.GAMMAcap, g.tec) with the left earlobe as a reference. The EEG signals were digitized at 512 Hz by amplifier (g. USBamp 3.0, g.tec.). The grouped EEG signals were averaged after the artifact detection and elimination of the bad segments. The averaged signals in the period of from 3.0 to 3.5 s before the go-signal was used to correct the baseline. The potentials were filtered using band-pass filter of 1-40 Hz.

## III. Results

Figure 4 shows the averaged transitions of the finger movements. The point-to-point reaching task was conducted properly in go trials with the sham-TMS. The abandonment of the motor intention was also successfully achieved in the pre-stop trials with the sham-TMS. In the go trials with TMS, the point-to-point reaching task was not disturbed. However, the finger moved involuntarily over the half way toward the target in the pre-stop-trials with TMS applied at 150 ms before the go-signal, that is, the TMS interrupted the abandonment of the motor intention.

Figure 5 shows the terminal positional shift of the finger-tip in the pre-stop trials with TMS and sham-TMS. The abscissa indicates the timing of TMS or sham-TMS from the go-signal. Diamond-shaped dots and square-shaped dots represent means of the terminal positions in the pre-stop trials with TMS and with sham-TMS respectively. Error-bar in each dot shows a standard deviation (S.D.). The TMS applied at 150, 100 and 50 ms prior to the go-signal elicited involuntary finger movement significantly compared to the trials with sham-TMS.

The brain activity related to the inhibitory interference of TMS to the abandonment of the motor intention was investigated with the evoked potentials. In order to emphasize the potentials concerning the abandonment of the motor intention and also to cancel the artifact caused by the TMS, the remainder potential of the pre-stop trials, which was the subtraction of the potential in the go trials from that in the pre-stop trials, was obtained. Figure 6 shows the remainder potentials of the pre-stop trials at FCz electrode with sham-TMS and TMS. The time of the go-signal was defined as 0 s. In the remainder potential of the pre-stop trials with sham-TMS, the positive peak was observed at 455 ms after the go-signal, whereas the potential at the same latency was attenuated in the trials with TMS. The 2D contour maps of the remainder potentials at the latency of the positive peak observed at FCz were shown in Fig. 7. The potential distributed around Fz observed in the pre-stop trials with sham-TMS was diminished by the TMS.

## IV. Discussions

In the present study, the intervention of the single-pulse TMS in the brain function concerning the abandonment of the motor intention was successfully achieved. The voluntary movement is supposed to be planned during BP observed mainly at the medial frontal scalp [3, 4]. As observed in the go trials in the present study, the motor process going along normal way in point-to-point reaching task is so robust that it is hard for the single pulse TMS to intervene. The motor process going forward from the planning produced in SMA and premotor cortex to the motor command composed in M1 is basic motor function. Such basic motor function should be done smoothly and rigidly to control the peripheral muscles cooperatively. If the voluntary motor function in the brain is disturbed by the external factor such as TMS, intentional movement with cooperative muscle contractions could fall into disorder. It is reasonable for the voluntary motor function in the central nervous system to be so protective against the external disturbance to achieve the complex control of the musculoskeletal system. In the voluntary movement, the motor planning produced before or during the movement should be altered or abandoned for the adaptation to the unexpected occasion or moving object as in the sports like baseball or tennis. The alteration of the motor planning has to be conducted rapidly to follow the quick change of circumstances. The brain process for rapid abandonment of the motor planning is presumed to be done in the way as a brake on the motor conduction. In the present study, the brain activity concerning the abandonment of the motor planning was observed as the positive potential at the front-central region of the scalp. This positive potential probably reflects the function of the motor cortex including SMA as the brake

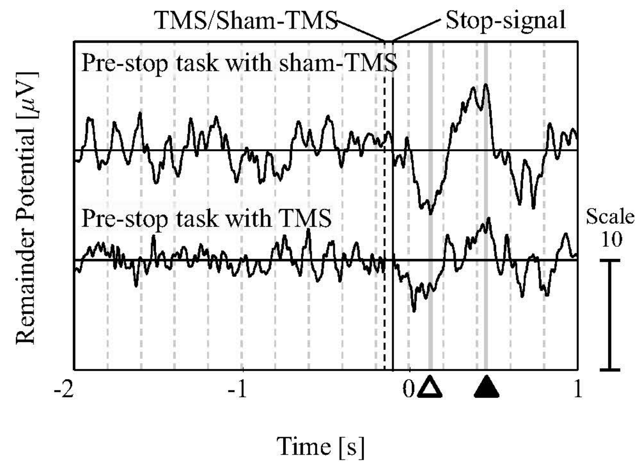



Figure 6. The remainder potential of the pre-stop trials with TMS and sham-TMS at FCz. The abscissa indicates the time with the go-signal as 0 s. The time of the Sham-TMS or TMS and stop-signal were indicated at 150 ms and 100 ms before the go-signal, respectively.

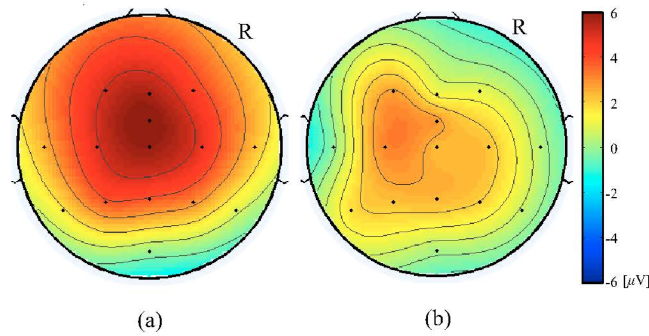



Figure 7. The 2D contour maps of the remainder potentials at 455 ms after the go-signal in pre-stop trials with (a) sham-TMS and (b) TMS

on the motor process. The TMS which interfered inhibitory to the abandonment of the voluntary finger movement lessened the positive potential. It is plausible that the single-pulse TMS inhibits the brain function of the voluntary brake on the motor process.

## V. CONCLUSION

In this paper, inhibitory interference in the voluntary abandonment of the finger movement by single-pulse TMS was attempted. The involuntary finger movement occurred with TMS applied at 150, 100 or 50 ms before the go-signal in the pre-stop trials with the stop-signal indicated at 100 ms before the go-signal. The positive potential observed at the fronto-central scalp with latency of around 450 ms in the pre-stop trials with sham-TMS was attenuated in the pre-stop trials with TMS. These results indicated that the single-pulse TMS applied around the stop-signal prior to the go-signal in the reaching finger task suppressed the brain function of the voluntary brake on the motor process.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