Hand Choice and Neuro-Rehabilitation
Causal Insights from tDCS and Somatosensory Stimulation

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Abstract: Hand choice is an unconscious decision we frequently make in daily life. However, when one arm becomes paralyzed, patients tend to rely solely on their non-paretic hand, limiting the use of the affected limb. Our research investigates whether we can modify the probability of hand choice by non-invasive stimulation.

Keywords: Stroke, Non-use, Posterior Parietal Cortex, Decision Making, Non-invasive Stimulation

Introduction

During daily activities, individuals unconsciously select the left or right hand to reach for an object. The choice of hand is mainly influenced by target-related information, including the location of the target (which hand can reach it with less effort) and shape and orientation of the target (which hand can grasp it more securely) [1]. However, the selection rate for each hand reaches equilibrium when the target-related factors are similar for the left and right hands [1]. The point of subjective equality (PSE) can be estimated as the virtual point in space where participants have an equal probability of using either hand to reach a target. PSE varies among individuals and tends to shift slightly to the left in right-handed individuals. Reaction time (RT) becomes prolonged around the PSE compared with that outside the PSE, suggesting the presence of competition [2]. Oliveira et al. applied single-pulse transcranial magnetic stimulation (TMS) to introduce perturbation to the left posterior parietal cortex (PPC) after the target presentation and before the onset of reaching, the interval when competition is likely to occur [2]. A significant reduction in right-hand selection rates and prolongation in RTs were observed for targets positioned around the PSE than for those that were not, impeding competition resolution. This indicates the potential for intervening in the hand-selection process around the PSE. In this paper, we introduce two experiments using non-invasive stimulation to explore whether we unconsciously influence their hand choice without adding cognitive load.

The purpose of the first experiment was to verify the causal relationship between PPC excitability and hand choice by increasing or decreasing the excitability of bilateral PPCs using transcranial direct current stimulation (tDCS). While Fitzpatrick et al. showed that fMRI activation correlated with hand - choice [3], this observation does not imply that the area is causally involved in the choice itself. Oliveira et al., in contrast, demonstrated that the left PPC is involved in the neural process of hand selection immediately before its - execution [2]. While single-pulse TMS provided causal evidence by disrupting an ongoing neuronal process, it did not reveal whether neuromodulatory changes in PPC excitability, caused by plasticity such as long-term potentiation (LTP) or depression (LTD), influence the decision regarding hand choice. It, therefore, remains unclear whether PPC excitability in itself is essential to hand choice. We increased or decreased the cortical excitability of PPC using tDCS and examined its online and residual effects on the hand-choice probability and choice reaction time.

The purpose of the second experiment was to determine whether short-term somatosensory electrical stimulation applied to the unilateral wrist at the time of or immediately before target presentation influences the probability of selecting the stimulated hand for targets around the PSE, where the selection rate is in equilibrium, and whether short-term somatosensory electrical stimulation shortens or prolongs the RT during hand selection. The results of this study will provide insights into the causal relationship between neurophysiological interventions prior to target presentation and hand selection.

Practically, this work will facilitate biasing hand selection without conscious or deliberate effort by the individual through a simple and inexpensive method, with potential applications in the rehabilitation of upper limb hemiparesis.

Methods

In the first experiment, to determine whether the effects of PPC's activity are essential and/or symmetrical in hand choice, we increased or decreased PPC excitability in 16 healthy participants using tDCS and examined its online and residual effects on hand-choice probability and reaction time. Two stimulation conditions were assigned: (1) the left PPC was stimulated with a cathode and the right PPC with an anode (LCRA condition), and (2) the left PPC was stimulated with an anode and the right PPC with a cathode (LARC condition). A constant current of 2 mA (current density of 0.06 mA/cm2) was applied for a total of 10 min. A 4-cm-diameter target circle was randomly presented at one of nine positions on a semicircle situated approximately 27 cm away from the start position. The participants were instructed to reach the target with either hand as quickly as possible within 650 ms of target presentation. The unused hand was required to be retained in the initial position. One block consisted of 108 unimanual reach trials (nine targets on the semicircle displayed 12 times), six bimanual reach trials, and six fixation reach trials presented in a pseudo-random order. The participants performed two blocks before (PRE), during (DURING), and after (POST) the stimulation.

In the second experiment, to examine the effect of prior somatosensory stimulation on the hand-choice process,14 right-handed healthy adult participants were asked to reach given targets using either the left or right hand as quickly and accurately as possible. The targets were presented at nine random positions on the semicircle. Unilateral stimulus (right and left wrist), bilateral stimulus (as the control condition), and no-stimulus conditions were randomly assigned 18 times for each target position. The stimulus intensity was set at 80% of the motor threshold, and the stimulus comprised five trains of 1-ms electrical pulses, with a 20-ms inter-pulse interval. The target was presented at 0, 300, or 600 ms after the somatosensory electrical stimulation.

In both experiments, the PSE was estimated using logistic regression, representing the point at which participants were equally likely to use either hand to reach the targets.

Results

The results of the first experiment showed that after the right PPC was stimulated with an anode and the left PPC with a cathode, the probability of left-hand choice significantly increased, and reaction time significantly decreased. However, no significant changes were observed with the stimulation of the right PPC with a cathode and the left PPC with an anode. These findings, thus, reveal the asymmetry of PPC-mediated regulation in hand choice [4].

The results of the second experiment showed that unilateral wrist stimulation significantly increased the probability of choosing the stimulated hand and led to a faster reaction time compared to bilateral wrist stimulation and no-stimulation conditions. The results suggest that prior somatosensory stimulation has a significant effect on the hand-choice process, effectively promoting the selection of the stimulated hand [5].

Discussion

The first experiment demonstrated that the probability of left-hand choice increased and that of right-hand choice decreased significantly after stimulation under LCRA condition. A similar but marginally significant change in choice probability was also observed during the stimulation, thus, indicating that the decrease in the excitability of the left PPC and the increase in the excitability of the right PPC are essential to enhance left-hand choice. Our results are consistent with those of Oliveira et al. [2]; they reported that single-pulse TMS disruption of the left PPC just prior to the initiation of a reaching action increased the probability of left-hand use, which suggested the asymmetrical involvement of PPCs on hand choice. LTP or LTD of synapses are reportedly involved in the residual anode or cathode effects of tDCS, - respectively; such plastic changes in the synaptic transmission of the left and right PPCs by tDCS may underlie the observed influence of PPCs on hand choice.

In the second experiment, somatosensory electrical stimulation of the left or right unilateral wrist at or immediately before the target presentation increased the probability of choosing the stimulated hand. When the target was positioned around the PSE, the RTs were significantly shorter in the left and right wrist stimulation conditions than in the bilateral wrist stimulation condition. Electrical stimulation to the wrist may influence the neural processes involved in hand selection earlier than the visual processing of the target information, considering the latency of the visual-evoked potentials. The visually presented target information is processed through a pathway via the V1 to the PPC and PMC. It typically takes approximately 100 ms to reach V1. Evoked potentials are observed around the frontal and parietal regions with a latency of 150–200 ms following the onset of the visual stimulus (N155/N180). In contrast, previous studies showed that an early component of the SEP appeared in the primary somatosensory cortex and PPC, with latencies of 20–30 ms and 100 ms, respectively. Similarly, Fujii et al. used EEG to investigate the effect of electrical stimulation of the median nerve at the wrist and observed SEPs in the contralateral parietal and frontal EEG channels of P3,4 and F3,4, with a latency of approximately 30 ms [6]. The stimuli in this study produced an SEP peaking at approximately 30 ms in the C4 region, expecting that the stimuli reached the parietal and/or frontal regions before the target information did, even when the target was presented just after the electrical stimulation.

Conclusions

These results highlight the potential of using non-invasive stimulation techniques in stroke recovery to promote the use of the paretic hand.

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