博士論文の要約

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学位論文題名

The Mechanism of Audiovisual Cross-Modal Conflict: Establishment of Neuropsychological Evidence and Application for Non-Invasive Neuromodulation Techniques

（視聴覚クロスモーダル葛藤のメカニズムの解明
−神経心理学的エビデンスの確立と非侵襲的ニューロモジュレーション技術の応用−）

Background: The sensory world is complicated in everyday life. Visual and auditory stimuli are two primary sensory modalities in our lives. Faced with this complex and sometimes conflicting information, people would be distracted by irrelevant information and ignore the relevant information as a result of cognitive conflict caused by unimodal (visual or auditory) or cross-modal (visual and auditory) information, thereby lowering the quality of human life. Cognitive control mechanisms allow individuals to focus on the relevant information and suppress the irrelevant information when meeting a cognitive conflict. The frontoparietal cortexes, especially the ventrolateral prefrontal cortex (VLPFC) and inferior parietal cortex (IPC), have been shown to play an important role in this process. Nowadays, cognitive conflict effects within unimodality are well characterized. In contrast, relatively little research has been conducted with cross-modal paradigms, and few neuroimaging studies have focused on cross-modal conflict, which has been shown to play an important role and is more active when there are distractions. Recently, there has been a dramatic increase in the use of transcranial electrical stimulation (tES) techniques to improve cognitive performance

by modulating cortical excitability. Among them, transcranial direct current stimulation (tDCS) is the most commonly used due to its powerful effect in a polarity-dependent manner. In addition, transcranial random noise stimulation (tRNS), a relatively new tES, has grown in popularity and could produce more significant and dependable neuromodulatory effects. However, the effectiveness of tDCS and tRNS on the interference effect of cross-modal conflict has not been thoroughly investigated.

Aims: In this thesis, Study 1 aimed to investigate the two types of cross-modal conflict that cause semantic competition (focusing on vision while ignoring auditory distractors and focusing on audition while ignoring visual distractors) through a single working memory task and its brain activity. Study 2 examined the effectiveness of tES techniques during cross-modal inhibition on the right inferior frontal gyrus (rIFG), one of the key brain areas identified in Study 1.

Study 1

Methods: 31 healthy, right-handed, young males (mean age=23.08±1.91) were recruited. Two types of paced serial addition test (PSAT), paced auditory serial addition test (PASAT), and paced visual serial addition test (PVSAT), were performed under distractor and no-distractor conditions. In the distractor condition, one of the PASAT or PVSAT was utilized as a target task, while the other was used as a distractor stimulus. In addition, the concentration of oxygenated hemoglobin (Oxy-Hb) changes in the bilateral dorsolateral prefrontal cortex (DLPFC), bilateral ventrolateral prefrontal cortex activity (VLPFC), and bilateral inferior parietal cortex (IPC), based on previous studies, were measured during PSATs by functional near-infrared spectroscopy

(fNIRS). To investigate the interfering effect of cross-modal conflict, the repeated measures analysis of variance (ANOVA) was used. Moreover, Pearson's product-moment correlation analyses were used to examine correlations between Δtask performance accuracy of PASAT and PVSAT (with distractor – with no-distractor) and ΔOxy-Hb changes (with distractor – with no-distractor) of them in each brain region.

Results and discussion: Behavioral results showed a significant decrease in task performance only in the PASAT, but not in the PVSAT. The results of Oxy-Hb changes showed a significant increase in the PASAT with the distractor conditions compared with the PASAT with the no-distractor condition in the bilateral VLPFC and IPC, but not in the PVSAT. Additionally, only in the bilateral IPC of the PASAT were there significant positive correlations between Δtask performance accuracy and ΔOxy-Hb changes. These results suggest that performance on the auditory task is considerably impaired by visual cross-modal conflict, the modality differences in filtering mechanisms may be one factor causing this asymmetrical interference effect of the distractor. Furthermore, PVSAT could be approaching a ceiling effect, which would result in no significant cross-modal interference effects in the visual task. Additionally, the strong modality bias—visual dominance in adults—that results in visual stimuli made it easier to produce an interference effect. As assessed through fNIRS, the visual cross-modal conflict activates the bilateral VLPFC and IPC more than the no-distractor condition and auditory cross-modal conflict. Additionally, changes in brain activation of the bilateral IPC correlated positively with changes in task performance accuracy during the PASAT. These results imply a critical function for the bilateral VLPFC and

IPC in reducing the interference effect of visual cross-modal distractors. While the current study did not report the difference between the left and right regions in all ROIs, which may be associated with the task difficulty. Therefore, more studies could use neuromodulation methods (such as tES, TMS, etc.) to investigate the functional differences between the hemispheres of these brain areas and how each brain region is engaged in inhibiting cross-modal distractors. Moreover, in order to gain a deeper understanding of the interfering effect of cross-modal conflict and its neural mechanisms, future studies should also look into the impact of task difficulty and how semantic and non-semantic cross-modal conflict differ in the auditory and visual cross-modal interference effect.

Study 2

Methods: In a randomized, double-blind, cross-over, placebo-controlled study design, 12 healthy, young, right-handed subjects (5 males and 7 females, mean age=21.75±0.75) were recruited. All participants experienced three types of stimulation in random order on three separate days: tDCS (2 mA anodal tDCS for 20 min), tRNS (2 mA high-frequency tRNS (100–640 Hz) + 1 mA direct current offset (DC-offset) for 20 min), and sham stimulation over the rIFG. Before, during, and after stimulation, participants repeatedly performed PASAT tasks including three conditions: no-distractor, semantic distractor, and non-semantic distractor. Meanwhile, in the baseline and offline periods, we measured behavioral performance (accuracy) and neurophysiological response (event-related potential, ERP) by using electroencephalography (EEG). The amplitudes of N200 and P300 were selected as task-related responses and analyzed. To investigate

which stimulus type is more effective for the inhibition of cross-modal conflict, a three-way repeated-measurement ANOVA with stimulation type (sham, tDCS, and tRNS with DC-offset), time (baseline, online, and offline), and task type (PASAT, PASAT with semantic distractors, and PASAT with non-semantic distractors) as within-subject factors was applied to behavioral and neurophysiological outcomes.

Results and discussion: The results showed the tDCS on the rIFG had a wider effect than the tRNS with DC-offset on the rIFG, regardless of the task type and time period, and specifically improved the performance of the PASAT with non-semantic distractors and decreased N200 amplitude related to the conflict monitoring mechanism, while the tRNS with DC-offset on the rIFG had a specific effect on the PASAT with semantic distractors and increased P300 amplitude related to the inhibitory process involved in inhibitory processing. These results demonstrate that non-invasive brain stimulations with tDCS and tRNS are useful techniques for improving inhibitory control during stimulation, but the effectiveness depends on the task type and time period. A single session of anodal tDCS on the rIFG had a wider effect than tRNS on the rIFG with DC-offset regardless of the task type and time period and specifically improved the inhibitory performance for task-irrelevant distractor and decreased N200 amplitude related to conflict monitoring mechanisms. On the other hand, a single session tRNS with DC-offset on the rIFG had a specific effect on inhibitory control for task-relevant distractors and increased P300 amplitude which is a close link with inhibitory processing. These results demonstrate the importance of using tDCS and tRNS differently depending on the type of interfering stimulus. Future studies will be needed

to further validate these results by increasing the sample size and examining the differences in effectiveness in different age groups. It is also necessary to examine the effects of tRNS and tDCS in patients with impaired inhibitory control due to neurological and psychiatric disorders.