

学位論文の要旨

Abstract of Thesis

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学位論文題目 Title of Thesis (学位論文題目が英語の場合は和訳を付記)

Study on neural mechanisms underlying multisensory spatiotemporal integration across visual, auditory, and tactile modalities

多感覚時空間情報の統合を支える神経メカニズムの解明

学位論文の要旨 Abstract of Thesis

Sensory systems are a core component of brain health. In August 2022, the World Health Organization published a position paper outlining a comprehensive framework for understanding brain health. This framework formally recognizes sensory function, alongside cognition, social-emotion, and motor function, as a core component of brain health. Notably, our senses do not function independently. In this complex and multisensory world, we are constantly receiving various sensory inputs, and these inputs are constantly interacting with each other. These interactions can occur within a single sensory modality, such as the integration of multiple visual cues, or across different modalities, as when auditory and visual signals are combined to form a unified representation. In this context, understanding how sensory information integrates and interacts is essential for promoting individual well-being, mental and physical health, and technological innovation. This series of studies aims to enhance our understanding of the mechanisms underlying the interaction between sensory information, as well as the influence of temporal and spatial factors, and other cognitive variables, including personality traits and associative memory training.

Experiment 1 examined the mechanisms of intra-modal integration, with a particular focus on how social communicative cues are processed within the visual modality. Additional attention was given to the potential influence of personality traits, specifically schizotypy, on such visual intra-modal interactions, as the recently proposed “hyperfocusing hypothesis” suggests that schizotypy is associated with a narrower but more intense allocation of attention. This study aimed to examine a key prediction of this hypothesis in a social communicative context, namely, that schizotypy may be associated with increased difficulty in overcoming the interfering effects of gaze. This may show in delayed responses to gaze-invalid targets. Here, the ERP index of P300 were recorded in a modified Posner cueing paradigm to examine this prediction in schizophrenia spectrum. Seventy-four healthy young adults with different levels of schizotypy participated in the experiment, in which they were asked to detect a target location cued by conflicting gaze and head directions. This result revealed that the gaze direction has a greater effect than the head orientation in terms of visual intra-modal integration. Second, we found that higher levels of schizotypy are related to an increased weighting

of gaze during visual integration, as reflected by increased susceptibility to distraction from gaze cues. Third, the relationship between schizotypy and visual intra-modal integration was mediated by the P300 amplitude. Higher SPQ scores were associated with reduced P300 amplitudes, which in turn predicted slower responses to targets invalidly cued by gaze direction. These findings support the view that, during visual intra-modal integration, P300 amplitude is associated with greater weighting of the gaze cue in schizotypy.

Experiment 2 explored the mechanism of inter-modal integration, with a specific focus on auditory and visual modality. Considering that audiovisual interaction and associative memory significantly overlap in their behavioral and neural mechanisms, we applied an audiovisual associative memory training protocol to investigate its potential influence on audiovisual integration. A total of 44 participants were recruited and randomly assigned to either the experimental group or the control group. Participants in the experimental group underwent audiovisual associative memory training while those in the control group completed item memory training. The training duration for both protocols was seven days with one and a half hours per day. Prior to and after training, participants in both groups completed an assessment for audiovisual integration using event-related potential measures with a simple detection task that required them to rapidly detect auditory, visual, or audiovisual stimuli. The behavioral data indicated a general effect of training, with both groups responding more quickly to unimodal stimuli after the seven-day intervention. EEG data showed a consistent pattern, with reduced amplitudes in both visual and auditory evoked components following the intervention. Moreover, a specific effect of training was revealed for audiovisual integration, as training-related modulation of early-stage audiovisual processing occurred only in the training group. This effect was absent in the control group. To sum up simply, these findings of Experiment 2 suggest that higher-level cognitive training may influence both unisensory and multisensory processing, which may help inform the design of more effective interventions in sensory processing.

Experiment 3 investigated the spatiotemporal integration of tactile information and its underlying mechanisms. In everyday life, coordinating the hand and foot on opposite sides of the body is often necessary for basic motor functions like walking or running. Studies on voluntary movement have indicated that contralateral hand-foot pairings exhibit superior interlimb coordination compared to ipsilateral ones. Nevertheless, it remains unclear whether this advantage also applies to passive temporal perception. This study examined the contralateral advantage through a temporal order judgment task by employing event-related potentials technique. Participants were presented with two rapid successive tactile stimuli, one to the hand and the other to the foot. They were asked to judge whether the hand was stimulated before the foot or the other way around. A contralateral advantage in tactile temporal order processing was revealed. Participants showed higher accuracy, quicker responses, and reduced just-noticeable differences when the stimuli were delivered to contralateral hand and foot. Although crossing the hand and foot impaired response times of temporal order judgment, this advantage remained still when responses were made with the right hand. The ERP results showed shorter latencies of centroparietal positivity (CPP) and lower amplitudes of both CPP and P1 components for contralateral hand-foot pairings, indicating that contralateral advantage occurs in both the early and late stages of tactile temporal processing. Overall, these findings of Experiment 3 suggest that contralateral advantage also applies to passive temporal perception, offering potential implications for developing sensorimotor interventions in clinical populations such as individuals with Parkinson's disease.

Taken together, this series of studies shed light on both the behavioral and neural mechanisms

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underlying sensory information interactions. These three experiments showed that sensory interactions are flexible and can be shaped by spatiotemporal features, cognitive factors, and personality traits, depending on the specific sensory channels involved. Moreover, the ERP results further indicate that the time course of these influences working on sensory interaction varies with the stimuli used, the task applied, and the nature of the sensory modalities engaged. Overall, these findings deepen our understanding of the mechanisms underlying sensory interactions and have meaningful implications for both clinical and healthy populations. They may help further understand sensory and temporal processing impairments in populations such as individuals with Parkinson's disease and schizophrenia, while also informing the development of more effective and targeted training-based interventions to improve brain health in both healthy individuals and clinical populations.

Keywords: intra-modal integration, cross-modal integration, tactile spatiotemporal processing, ERPs