論文の内容の要旨

Psychophysical and neural properties of context-dependent duration perception

（文脈依存的な時間長知覚における心理物理学的及び神経科学的特性）

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Perceiving duration of external events is vital for various human behaviors (Buhusi & Meck, 2005). However, the temporal information given by sensory systems is sometimes too impoverished to perceive event durations appropriately. The timing system thus utilizes various clues to optimally estimate event durations. In particular, considerable research has focused on how the temporal context influences the perception of duration.

When stimuli with various durations are intermixedly presented, longer durations are underestimated and shorter durations are overestimated (Vierordt, 1868). This phenomenon, called the central tendency, suggests that the brain optimally encodes the event duration by taking into account the prior knowledge about how long events have occurred in the past (Jazayeri & Shadlen, 2010). In this thesis, I examined psychological (Study 1) and neural (Study 2) mechanisms for this optimal encoding process of duration.

In Study 1, I psychophysically investigated how stimulus modality and timescale affect the central tendency. In Experiment 1, participants were asked to reproduce sub-second (i.e., hundreds of milliseconds) or supra-second (i.e., several seconds) durations, defined by visual or auditory stimuli. The reproduced durations were linearly regressed to the stimulus durations, and the slope of the linear regression was used as an index for the magnitude of the central tendency. In the sub-second range, the magnitude of the central tendency was significantly larger for visual durations compared to auditory durations, while visual and auditory durations exhibited a correlated and comparable central tendency in the supra-second range. In Experiment 2, I examined whether the modality-dependent central tendency in the sub-second range resulted from differences in the temporal sensitivity between the visual and auditory systems. The stimulus durations in the reproduction task were determined based on the participant's performance in the duration discrimination task. Even when the ability to discriminate durations was controlled across modalities, visual durations exhibited a larger central tendency than auditory durations in the sub-second range. Furthermore, the magnitude of the central tendency for visual and auditory sub-second durations was significantly correlated. These results suggest that a common modality-independent mechanism is responsible for the supra-second central tendency, and that both the modality-dependent and modality-independent components of the timing system contribute to the central tendency in the sub-second range.

In Study 2, I examined the neural implementation of the optimal duration encoding by using functional magnetic resonance imaging (fMRI). Neuroimaging studies have revealed that distinct brain networks are recruited in the perception of sub- and supra-second durations (Lewis & Miall, 2006; Wiener et al., 2010). Study 2 aimed to examine how the intermediate duration between sub- and supra-second durations is processed in the brain, and how the temporal context modulates the timing neural activity. In the experiment, I measured the neural activity while participants reproduced the duration of visual stimuli. The stimulus duration was either sub-second, one-second, or supra-second. One-second durations were intermixed with sub-second durations in a half of scans, and with supra-second durations in the other half. Thus I could compare neural activities for one-second durations under different temporal contexts. Firstly, the results replicated the findings of previous studies in showing that separate neural networks are recruited for sub- versus supra-second time perception: motor systems including the motor cortex and the supplementary motor area were activated during sub-second perception, and the activations in the frontal, parietal, and auditory cortical areas were observed during supra-second perception. Secondly, I demonstrated that the one-second perception activated both the sub- and supra-second networks. Furthermore, the supra-second network was more involved in the one-second processing when one-second durations were intermixed with supra-second durations, and the sub-second network was more involved in the one-second processing when one-second durations were intermixed with sub-second durations. These results indicate that the sub- and supra-second timing systems overlap at around one second, and cooperate to optimally encode duration based on the hysteresis of previous trials.

In Study 2, the inferior parietal lobule (IPL) in the supra-second network exhibited a context-dependent timing activity. The IPL has been suggested to process the spatial and temporal "magnitude" of external events such as size, numerosity, and duration (Walsh, 2003). Study 1 demonstrated that the central tendency is modality-independent in the supra-second range, and the central tendency in the supra-second duration could be interpreted in a more general computational process beyond duration perception. If the IPL is also involved in the optimal encoding process of various perceptual attributes other than duration, the central tendency in duration perception should share a common feature with the central tendency in other perceptual attributes. The present doctoral thesis gave understandings as to psychological and neural properties of context-dependent duration perception, and will have expandability to a broader optimization process of our perception.