論文の内容の要旨

Spatiotemporal organization of whole-body rhythmic movement using self-generated information

（自己生成情報を用いた全身リズム運動の時空間的組織化）

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Introduction

Human movement may be considered as one of the self-organizing phenomena, which results from the interaction between the body and environment. This dynamical view leads a new way of exercise support using environmental information. Rhythmic auditory stimuli are expected as the environmental information to enhance motor performances in practical settings. In particular, it has been reported that spatiotemporal stability of rhythmic movement increases when the movement is coordinated with a rhythmic auditory stimulus.

This rhythmic coordination between an auditory stimulus and human movement has been investigated using dynamical system approach, and known to obey general self-organization dynamics. That is, self-organizing pattern formation is observed as abrupt transition of phase relation between an auditory stimulus and human movement when movement frequency increases. This transition is called *phase transition* and observed in various coordination of human movement. The movement stabilization might be due to this self-organizing pattern formation between an auditory stimulus and human movement.

Meanwhile, not only external devices but also vocalizations can generate a rhythmic

auditory stimulus. One question, raised from that, is whether vocalizations that generate a rhythmic auditory stimulus can increase the stability of one's own movement through the self-organizing pattern formation.

The general purpose of this thesis is to explore whether self-generated information through vocalizations can organize stable whole-body movement. To achieve this end, four experiments were conducted.

Experiment 1

Previous studies have reported that phase transition occurs in auditory-motor coordination. Therefore, I investigated the coordination dynamics between vocalizations and whole-body movement. The phase transition paradigm needs to manipulate movement frequency continuously within a trial. Since it is difficult for participants to control movement frequency systematically without pacing signals, I aimed at capturing a stable coordination pattern and manipulated movement frequency in separate trials. Two coordination patterns between vocalizations and whole-body movement (hip, knee, and ankle joint flexion-on-the-voice vs. joint extension-on-the-voice) were explored at movement frequencies of 80, 130, and 180 beats per minute (bpm). Analyses of phase relation between vocalizations and whole-body movement revealed distinct differences between the coordination conditions: At higher movement frequencies, the phase relation in the extension-on-the-voice condition deviated from the intended phase relation. However, the phase relation of the flexion-on-the-voice condition was maintained even when movement frequency increased. These results indicate that there was a stable coordination pattern in the flexion-on-the-voice condition. That is, the coordination between vocalizations and whole-body movement obeys a general self-organization dynamics.

Experiment 2

The aim of Experiment 2 was to explore whether the variability of whole-body movement and vocalizations is reduced when two movements are coordinated in a stable coordination pattern (flexion-on-the-voice). The variability in whole-body movement and voice-onset intervals was compared between two conditions: one related to tasks performed in the stable coordination pattern (coordination condition), and the other related to tasks performed independently (control condition). The results showed

that the variability of whole-body movement and voice-onset intervals was smaller in the coordination condition than in the control condition, suggesting mutual stabilization between rhythmic vocalizations and whole-body movement via coordination within a stable pattern.

Experiment 3

A vocalization has two aspects; a vocalization as movement and a voice as an acoustic stimulus. The focus of Experiment 3 was the effect of vocalizations as movement on a stable coordination pattern and mutual stabilization between vocalizations and whole-body movement. I investigated this effect by interfering auditory feedback using white noise masking. Two coordination patterns between vocalizations and whole-body movement (flexion-on-the-voice vs. extension-on-the-voice) were investigated under interference with auditory feedback. I also investigated whether vocalizations reduce the variability of whole-body movement under the interfered condition. Movement frequencies were set at 80, 130, and 180 bpm. As with the results of Experiment 1, the phase relation between vocalizations and whole-body movement deviated from the intended phase relation in the extension-on-the-voice condition but not in the flexion-on-the-voice condition when movement frequency increased. The reduced variability of whole-body movement was observed even under interference with auditory feedback. These results suggest that the coordination between vocalizations as movement and whole-body movement obeys general self-organizing dynamics, and movement of vocalizations reduces the variability of whole-body movement.

Experiment 4

Practical motor performances are often required to be in accordance with environment that changes with time. I explored the effect of vocalizations on this coordination ability using the auditory-motor coordination of whole-body. I investigated whether vocalizations reduce the variability of the coordination. A vocalization was performed at a 1:1 frequency locking with a metronome beat. The results showed that vocalizations reduced the variability of the coordination in the flexion on the beat condition, but not in the extension on the beat condition. These results indicate that vocalizations can stabilize the coordination under the specific coordination pattern.

Summary

This thesis revealed that vocalizations and whole-body movement coordination obeys general dynamical principles of self-organization, and mutual stabilization occurs via coordination within a stable pattern. These results were also obtained in the coordination between movement of vocalizations and whole-body movement. Furthermore, vocalization was effective for the auditory-motor coordination of whole-body. Therefore, this thesis demonstrated that vocalizations could organize stable whole-body movement. That is, certain motor and coordination tasks are stabilized by vocalizations. The findings of this thesis are useful for performance improvement of sports and dance, and also can be for music performance and rehabilitation.