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Temporal co-creation between self and others with multi-sensory inputs

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Abstract

This study uses cognitive psychological experiments to elucidate human temporal co-creation with environments or other people. Time series analyses of alternate tapping with constantly paced computer signals (Experiment 1) show some modality-specific features when the participants receive signals through visual or auditory means. Subliminally perturbed signals using sine-wave function (Experimental 2) were revealed as having effects on the participants' tapping performance especially in visual perturbation. Results from interpersonal tapping tasks (Experiment 3) reveal the emergence of temporal co-creation, including entrainment and mutually complementary relationships depending on the sense modality. These findings can be the underlying basis of the design for natural temporal communication between human and artifacts.

Keywords: Finger tapping; Temporal co-creation; Entrainment; Cognitive psychology

1. Introduction

The traditional approach in cognitive psychology observes a human and understands its mechanism from an information-processing standpoint. Human activity, however, cannot be evaluated merely from the standpoint of individual activity; it should be also evaluated in terms of interactions among humans and the environment, humans and humans, and humans and artifacts. Recently, many researchers in this field, including the authors of this paper, have specifically addressed the interaction and dynamic systems of human activity. The concept of emergence and co-creation is a new approach to understand and utilize these interactions. Ueda [1] has proposed emergent synthesis-based co-creation engineering where bidirectional interaction among a human, an artifact, and an environment is explicitly considered to break through the limitations of existing artificial systems. This study observes human temporal activity as temporal co-creation with environments or other people.

We communicate with the environment in real-time and co-create a rhythm with other people as evidenced in conversation, locomotion and musical ensembles. Real-time rhythm production, however, is complex because various time lags arising in the process of sensory-sensory integration, sensory-motor coordination, and motor execution must be overcome. Humans receive timing information mainly through visual, auditory and tactile receptors, but it remains unclear how the neurons, which are responsible for processes of perceptual modalities in the brain, determine the mutual timing of their firing [2]. It is also uncertain how modality specific differences are manifested in the process of sensory-motor coordination and temporal motor control of action [3]. In terms of temporal accuracy, auditory-guided motor control is well known to be more accurate than visually guided motor control [4,5]. Visually guided motor control such as that for locomotion or dance, however, is also considered adaptive to environmental changes. It is therefore important to investigate not only accuracy but also modality-specific features underlying temporal co-creation. In addition to the processing time-lags, we also need to manage the time-lag between time perception and motor control because time perception usually

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takes much more time than temporal motor control [6–8]. These problems are important in the context of active and interactive communication because communication, by its nature, includes two contrary aspects: controlling others and being controlled by others. In other words, active and passive controls exist simultaneously when we co-create a rhythm with environments or other people. Active control of action is known to take a longer time than passive one from the standpoint of human motor control [4]. Understanding temporal communication according to the motor control theory is complex because that communication is interactive; it also includes bidirectional processes.

On the other hand, entrainment—which forms respective biological relations among humans and humans, and humans and artifacts—has received attention in the fields of human interfaces as the emergence of cooperation [9–11]. Some studies based on self-organization theory, for instance, have shown strong coupling between humans and environments in locomotion [12]. Nevertheless, it remains unclear how temporal co-creation always occurs in this style because entrainment seems less suitable for active or voluntary aspects of human communication than for passive or involuntary one, such as automatic synchronization. Additionally, previous technical applications of the entrainment theory gave little thought about sensory differences [13,14].

This study examines the nature of human temporal co-creation with the environment or other people using an alternate-tapping task, in which participants are in a mutual dependence relation, to generate a rhythm. First, we aimed to define the role of sensory information (visual or auditory) in rhythm production. In the introduced experiments, we set two external signal conditions (visual or auditory) and three internal feedback conditions (visual or auditory own feedback, or no feedback).

Second, we aim at finding differences in thresholds between the time perception and temporal motor control of action using visual and auditory stimuli. Recently, it has been pointed out that the visual system has two different pathways for perception and action. Goodale and Milner [15] mapped this distinction onto the two prominent visual pathways that arise from early visual areas in the primate cerebral cortex: a ventral ‘‘perception’’ pathway and a dorsal ‘‘action’’ pathway. However, this distinction between perception and action has been confirmed mainly in the spatial aspect—spatial perception and spatial motor control of action—rather than in the temporal aspect. On the other hand, previous studies using auditory temporal perturbation have revealed rapid adaptations of subjects to subliminal temporal changes [16,17]. However, differences between visual and auditory perturbations have been not clarified. It is important to find the level at which participants co-create rhythms with the environments. We used several varieties of perturbed signals around the perceptual threshold.

Third, we seek to observe temporal co-creation between two people and evaluate their relationship. It is therefore important to evaluate the relationship of two people aside from the accuracy of performance. This standpoint, unfortunately, has been less common in the field of the cognitive psychology: previous studies of time generation using finger tapping task have mainly targeted individual performance and measured accuracy and variability (reviewed in [18,19]). Although some studies have targeted the cooperative rhythm production of two people (Mates, Radil and Pöppel named it cooperative tapping [20]), they reported that the subjects' performances were lower in accuracy under the cooperative condition than under the self-paced condition. Although accuracy is just an attribute to evaluate performance, other analyses, including time series analyses, are deemed necessary to evaluate the cooperation or temporal co-creation. Moreover, Mates et al. used a synchronization task in which subjects receive external signals (metronome click and their partners' responses) and internal signals as their own feedback at about the same time. Although the synchronization task is popular in this research field, it is confusing for subjects to distinguish their action or their partner's action from the metronome. Faced with such tasks, subjects often fall into undesirable strategies: they merely intend to keep their own pace or wait for their partner's rhythm.

We conducted three experiments in which participants were instructed to tap with their fingers alternately with the constant-paced (like a metronome) external signals (Experiment 1), temporally perturbed external signals (Experiment 2), and their partner's response signals (Experiment 3) following short-time pace-maker signals (eight signals). The alternate-tapping task that we employed here is simpler. It more easily produces a mutual dependence relation than the synchronization task.

In the introduced experiments, we set two external signal conditions (visual or auditory) and three internal feedback conditions (visual or auditory own feedback, or no feedback). We aimed at defining the role of internal feedback information to distinguish oneself from other people or environments.

2. Experiment 1

In Experiment 1, we investigate the effects of the modality (visual or auditory) of the external and internal (the participant's own feedback) signals on their tapping performance.

2.1. Method

2.1.1. Apparatus and stimuli

All signals were produced and monitored using a special program on a computer (Dynabook G4/U17PME; Toshiba Corp.) via an interface (PH1210; DKH Corp.). The interface had 16 I/O channels and connected to a sound generator (custom-made by DKH Corp.) and a light-emitting diode (LED) device (Fig. 1). The temporal resolution of measurement was 250 μs.