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Two dynamics of anticipatory behavior in synchronization tapping

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Abstruct: It is well known that the sensory-motor coupling represents negative asynchrony phenomenon in which motion timing precedes the onset of stimulus. However, in such previous researches, the tapping task has been investigated by statistical analysis of synchronization errors. Therefore, in this report, we used time-series analysis and it was shown that anticipatory behavior in sensory-motor coupling is composed of two different dynamics corresponding to two types of anticipatory timing control.

Key Words: synchronization tapping task, negative asynchrony, time-series analysis

1. Introduction

The Man-machine interface is, so to speak, a kind of boundary between external events of the machine (e.g. operation by user) and internal ones (e.g. cascade of commands). From a same perspective, a human's interface which is boundary between external events of the human and internal events performs interesting behavior. In the human's interface, sensory-motor coupling between audio-visual or somatosensory inputs as external events and motor outputs as internal events perform predictive synchronization, actually sometime.

Even on simple task, predictive synchronization between mechanical response and cyclic tonal/photic stimuli as a pacing signal, so-called "Negative Asynchrony", is widely observed [1)2)3)]. It means that motor output precedes sensory input by several tens of milliseconds. This incognizable phenomena is outside the framework of the "serial" cascade of information flow, such as (1) sensory input, (2) processing, and (3) mortor output.

Such effect suggests temporal control is realized subjectively in internal parts of the interface. Some perceptual mechanism where time is perceived in the interface of hunam is not necessarily consistent with real-time in external parts of the interface.

By the same token, it is well known that two persons perform predictive motor behavior to facilitate synchronous with each other in a face-to-face communication [4)]. As just described, the human's interface manages synchronization with skill between real-time external events and subjective-time internal events. This framework has a possibility of predictive response on time lags.

One of simplest experiments on negative asynchrony described above is synchronization tapping task. This provides a subject with pacing signals as a tonal stimulus and records finger tappings as motor outputs. Using this, the asynchronous was prospected in studies by Mates and Pöppel [5)]. They controled interval of cyclic pacing signal between 300ms and 4800ms. They reported on decline in the probability of negative asynchrony over about 3000ms.

Besides, to focus on skilled temporal control and synchronous motor behavior which human attains, the tapping study which applies dual-task method was implemented [6)]. The study based on the attention capacity model (Kahnemann, 1973 [7)]) tried to find out whether predictive temporal control required higher brain function such as attention and working memory plays central roles in time perception about period for a couple of seconds [8)9)]. The experiment is composed of tapping task and secondly task which demands attentional resouech. Results of the study suggest following three aspects. The temporal control system influenced attentional resouce is concerned tap timing in longer interval region. Meanwhile, the temporal control is implicitly achieved without this mental resource in shorter interval region. Beside, by analyzing auto-correlation C(1) obtained from fluctuation of asynchrony, this experiment suggest the possibility of performing temporal control with feedforward in fast tapping.

The mean and variance (standard deviation) are static measures that marginally reflect temporal structure in the time-series data. But auto-correlation discribed above led analyzing procedure of tapping task to investigate these structure. If we extend C(1) auto-correlation to C(k) one, this becomes synonymous with frequency analysis. Even if no application of a frequency analysis against fluctuation of tapping asynchrony has been performed, the analisys was applied for fluctuation of tapping pressure [10)]. This study showed rough criterion in order to distinguish healthy and handicapped person.

Our new research which considers the fluctuation of asynchrony as the time-series behavior between finger taps and tonal stimulus, uses power spectrum toward revealing dynamics of the precess.

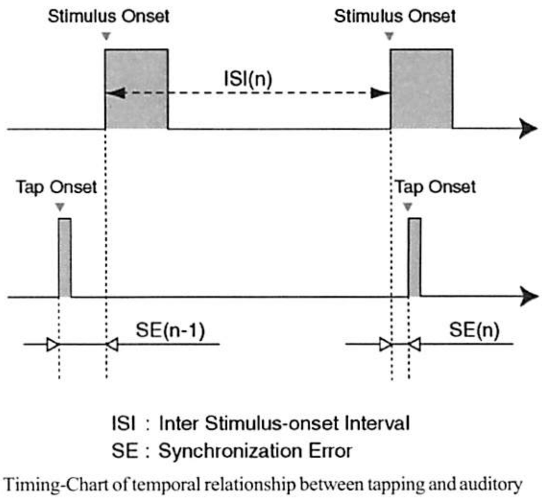

Fig.1 Timing-Chart of temporal relationship between tapping and auditory stimuli.

2. Method

2.1 Experiment

Accordint to former synchronized tapping task [5,6], our measurement system povided subjects with a cyclic pacing signal as the tornal stimuli, and detected right index finger tappings as their responses to an accuracy of 1/1024 second. The pacing signal has a 100ms duration and a 500Hz frequency.

The nine participants in this research are composed of trained male volunteers without hearing disability and movement disorder in their finger. They are dextral and twentysomething students. These subjects are required to tap an index finger against mechanical switch in exact timing with pacing signal. They are previously barred from moveing parts of their bodies except right index fingers (e.g. foot tapping) in rhythm and from dividing given intervals (e.g. dividing 6000ms interval into 4 parts of 1500ms intervals) in their minds.

2.2 Parameters

A time difference between the auditory stimulus onset and the finger tap onset was defined as the Synchronization Error (SE). A predictive tapping makes the SE negative. A time difference between the neighboring two auditory stimuli was defined as the Inter Stimulus-onset Interval (ISI). ISI is controlled variable and SE is measurand in this experiment (see Fig.1).

2.3 Procedure

The ISI was set intermittently to 450, 600, 900, 1200, 1800, 2400, 3600, 4800, 6000ms in each trial and was fixed throughout the trial. We povided subjects with 120 auditory stimuli and measured 100 SEs without lead 15 SEs and final 5 SEs.

By calculating auto-correlation C(k) obtained from

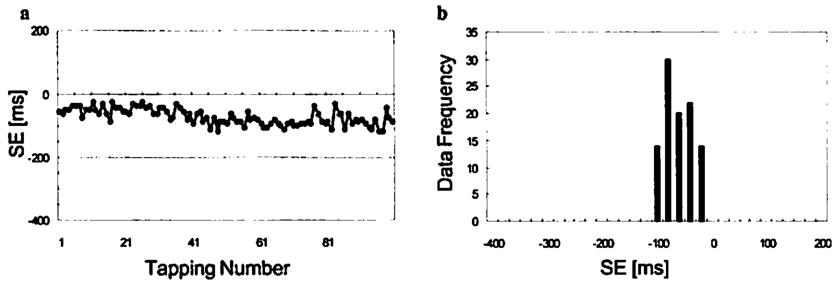

Fig.2 Raw time-series data (left) and its histogram (right) of SE in sample-A. ISI is 450 [ms].

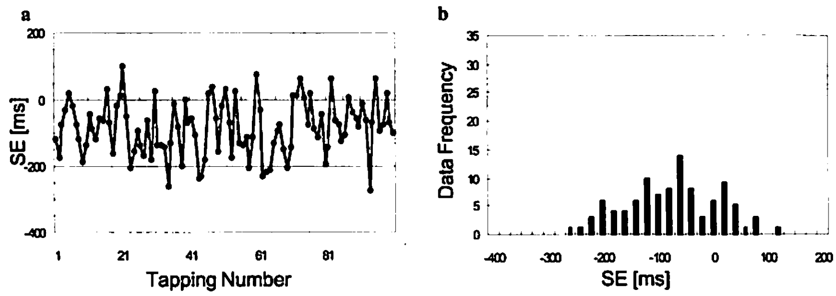

Fig.3 Raw time-series data (left) and its histogram (right) of SE in sample-B. ISI is 2400 [ms]. Sample A and B are provided by same subject.

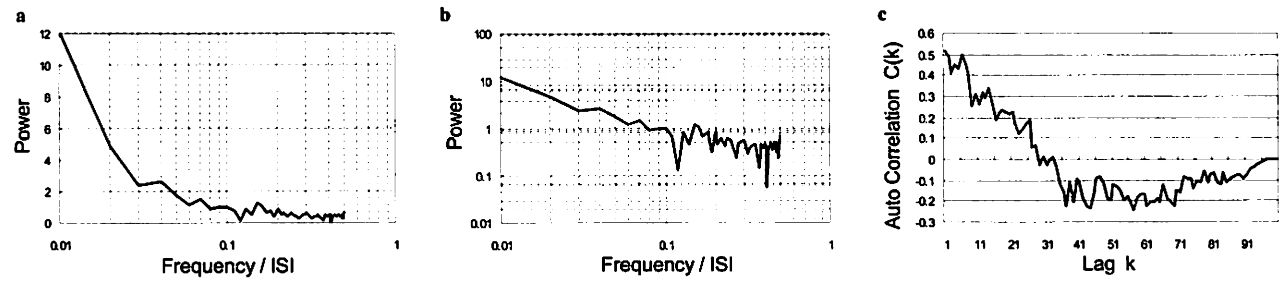

Fig.4 Power spectrum (left, center) and auto-correlation (right) of SE in sample-A.

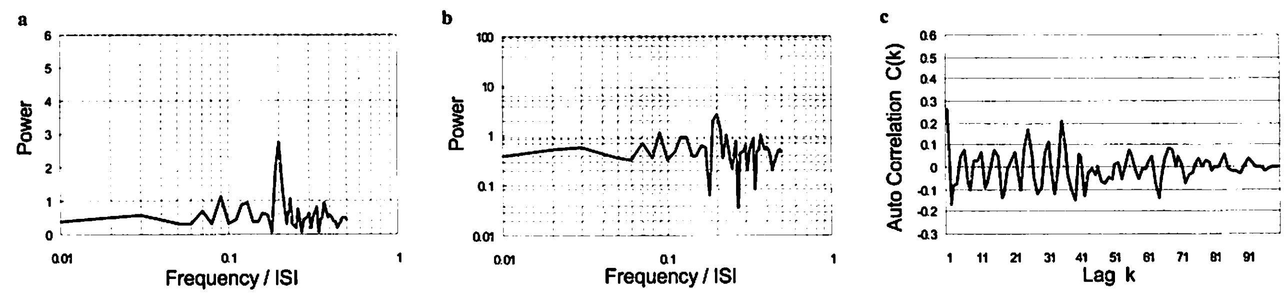

Fig.5 Power spectrum (left, center) and auto-correlation (right) of SE in sample-B.

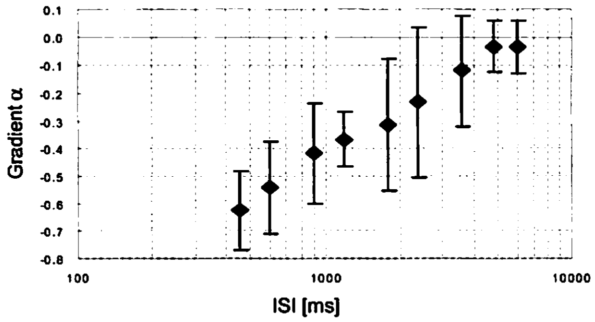

Fig.6 Relationship figure between ISI and gradient α.

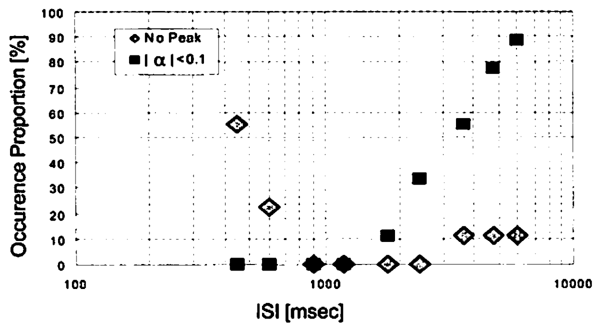

Fig.8 Occurence proportion of two features on power spectrum. Black square is ratio with white noise (gradient α < 0.1). Gray mascle is ratio without significant peak.

normalized time-series asynchrony (SE), we have analyzed power spectrum of SE by discrete Fourier transform (DFT).

3. Result

3.1 Frequency response

Two sets of data examples is shown in Fig.2 and Fig.3 Each figure is composed of (a) raw time-series SE and (b) histogram of SEs. In fact, these are two typical examples of processed time-series SE (see Fig.4 and Fig.5). Each figure is composed of (a) raw SE, (b) single logarithmic plot, and (c) double logarithmic plot.

On Sample-A(ISI=450ms), the relative performance of power computed by DFT has an inverse function of frequency (see Fig.4b). This relationship between the frequency and the power, we call "Inverse-Dynamics", proves that fluctuation of asynchrony depends on no unique frequency. Reducing to the terms, lower frequency contributes fundamentally to fluctuation pattern in power spectrum. This is a sort of self-similarity. The long-term fluctuation which sustains longer than neighboring tap elevates the auto-correlation coefficient between C(1) and roughly C(20) (see Fig.4c).

On Sample-B(ISI=2400ms), the power spectrum present a combination of flat spectrum as white noise and one prominent peak which frequency is nearly equivalent to five times of given ISI (see Fig.5a). In response to frequency peak, auto-correlation coefficient forms a peak every 5 lags between C(1) and C(41) (see Fig.5c). Especially, the C(36) exceeds 0.2, so it is regarded as 95% significant period component.

$$2Power(n) - Power(n-1) - Power(n+1) \geq 2.0 \qquad [1]$$

After reviewing samples which have statistically significant peaks of auto-correlation coefficient as just described, we decide to define the function [1] as a criterion of "significant" peak on power spectrum in this report. This frequency-dependent behavior that we call "Periodic-Dynamics" show fluctuation of SE to depend on ISI or pacing signals.

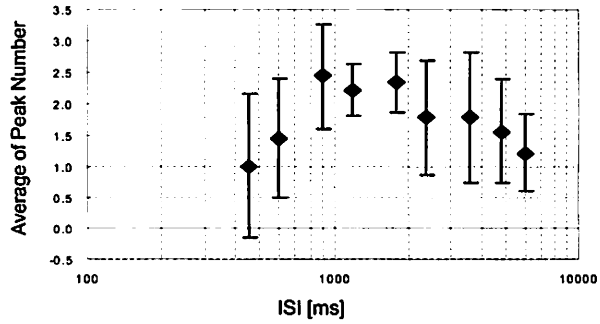

Fig.7 Relationship between ISI and mean counts of "significant peak".

3.2 Distribution of two characteristics

In order to have an overview about distribution of above two dinamics with respect to ISI, this experiense affords two figures.

First, we examine features of power spectra which has Inverse-Dynamics (see Fig.6). The gradient α is defined by a slope of least-squares method in double logarithmic plot between frequency and power. On highly ISI, decreasing in gradient α characterizes the power spectrum as white noise. On the contrary, the gradient α are 0.63 and 0.54 in ISI=450 and ISI=600.

Then, we examine features of power spectra which has Periodic-Dynamics (see Fig.7). Mean counts of significant peak with respect to ISI be formed of plateau shape which has broad hilltop between ISI=900 and ISI=1800. An appearance of peaks have a difficulty to perform at both high and low intervals of the pacing signal.

Fig.8 exhibits each charactoristic response to the ISI. The ISI ranges over from 900ms to 1800ms is accompanied with both of the dynamics. In longer ISI, Inverse-Dynamics appears with lower repetition. On the other hand, shorter ISI fail to preserve the Periodic-Dynamics.

4. Discussion

The distribution of Inverse-Dynamics shows less ISI to reduce the gradient α closer to -1. α = -1 means fluctuation of asynchrony possesses 1/f fluctuation. This comportment is found in various rhythms through nature, such as a period of steady walking motion [11], a heartbeat rhythm derives from the pool of pacemaker cells [12], and so on. It is not clarified why power spectrum of finger tapping in short ISI bears a similarity to those biological rhythms. But at least, the temporal control at fast tapping, especially shorter interval than 1sec, has long-term correlation.

Furthermore, a walking motion is produced by predominantly the Central Pattern Generator (CPG) and the reflex in the spinal chord. Such biological mechanism is known as a system which is regulated by the higher nerve center such as brainstem and cerebellum [13]. A pharmacologic blockade experiment points to possible role by parasympathetic nerve to heartbeat rhythm which possesses 1/f fluctuation [14].

Herewith, the combination of automatic rhythm generator and regulation from higher nervous system is popularly found among various biological rhythms involve the 1/f fluctuations.

However, in long ISI region, occurrence of Periodic-Dynamics which is subject to given frequency of pacing signal suggests the potential of interfering with temporal control by auditory feedback. An occurrence of this characteristic marks a sharp decline in short ISI region.

This conclusions reinforce following knowledge in former research. The negative asynchrony consists of two temporal controler [6]. In longer ISI, no fewer than 1800ms, the attentional resouce calls control into existence. On the contrary, the asynchrony is controlled by a feedforward structure, in shorter ISI, nor more than 1800ms.

5. Summary

In consequence of frequency analysis, we found two characteristics in perfomance of the negative asynchrony, such as Periodic-Dynamics and Invers-Dynamics. The former depends in good part on the frequency of pacing signal as the tonal stimuli. On the other hand, the latter is reliant on not such frequency but rather long-term temporal structure, such as frequency being in inverse proportion to power. Additionally, this report demonstrates the above two characteristics depends on the interval of auditory stimuli. Occerance proportion of each characteristics change with ISI independently.

Our new observational study on synchronized tapping task gives an account of time-series fluctuation of asynchrony between. This achieves domination over former statistic in determining the occerance proportion of above characteristics.

Meanwhile, our research group has constructed man-machine interfaces in line with the basic models of "Co-Creation" concept [15)-19)] and estimated them [20)21)22)]. The systems based on a model accomplishes rhythm synchronization through the medium of body movements. These systems also perform negative asynchrony. We expect an investigating the phenomena by this time-series analysis to serve as a stepping stone to construction of new Co-Creation model.

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