Two dynamics of anticipatory behavior in synchronization tapping

Tomoaki Komatsu and Yoshihiro Miyake

Tokyo Institute of Technology, 4259 Nagatsuta, Midori, Yokohama 226-8502, Japan
komatsu@myk.dis.titech.ac.jp

Abstract: 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. 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) motor 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 humam 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 synchronously with each other in a face-to-face communication. 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 Poppel. 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. The study based on the attention capacity model (Kahnemann, 1973) 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. 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. Besides, by analyzing auto-correlation of 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 analysis was applied for fluctuation of tapping pressure. 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 process.

![Fig.1 Timing-Chart of temporal relationship between tapping and auditory stimuli](image_url)
2. Method

2.1 Experiment

According to former synchronized tapping task studies, our measurement system provided subjects with a cyclic pacing signal as the tonal 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 moving 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 provided 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.

-3208-
Discussion

Presented in the Results section, we describe the influence of the frequency on the optical properties of the composite material. The optical properties are measured using a spectrophotometer, and the data is presented in the form of a graph. The graph shows the variation of optical properties with frequency and thickness of the composite material.

The analysis of the data indicates that the optical properties of the composite material are highly dependent on the frequency. The optical properties increase with an increase in frequency, and this trend is more pronounced for materials with higher thickness. The results are consistent with previous studies that have shown similar trends.

Future experiments will focus on understanding the underlying mechanisms that govern the frequency-dependent optical properties. The results of these experiments will be reported in a subsequent publication.
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 
controller 40. In longer ISI, no fewer than 1800ms, the 
attentional resource 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 performance 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. 
Occurrence 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 occurrence 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. 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.

Reference

1) L.T.Sterns: On the time sense, Mind, 11, 393/404 (1886)
2) P.Fruisse: sensorimotor synchronization of rhythms, In J. Requin(Ed.), 
Anticipation et comportement, Centre National, Paris, 233/257 (1966)
3) G.Achimseh, W.Prinz: Synchronizing actions with events: The role of 
4) Edward Titchell Hall: Dance of Life; The Other Dimension of Time, 
Anchor Press (1983)
5) J.Mates, T.Radill, U.Müller and E.Pöppel: Temporal Integration in 
Sensorimotor Synchronization, Journal of Cognitive NeuroScience, 6- 
4, 332/340 (1994)
6) Y.Miyake, Y.Onishi, E.Pöppel: Two modes of timing anticipation in 
synchronization tapping (in Japanese), Trans. of the Society of Instrument 
and Control Engineers, 38-12, 1114/1122 (2002)
7) Kahnemann.D: Attention and efforts, Prentice-Hall (1973)
8) A.Kagerer: Cortical involvement in temporal reproduction; evidence for 
differential roles of the hemispheres, Neuropsychologia, 40, 357/366 
(2002)
9) S.W.Brown: Attentional resources in timing: interference effects in 
concurrent temporal and non-temporal working memory tasks, Perception 
& Psychophysics, 59-7, 1118/1140 (1997)
10) H.Yoshinaga, S.Miyazimi, S.Mitske: Fluctuation of biological rhythm 
11) J.Hasdorf et al: Is walking a random walk?, Evidence for long-range 
correlation in stride interval of human gait, Journal of Applied Physiology, 
12) M.Kosayshi, T.Musha: 1/f Fractuation of heartbeat period, IEEE 
Transactions on Biomedical Engineering, 29, 456/457 (1982)
13) G.Taka: explore design principle on life system (in Japanese), 
14) Y.Yamamoto, Y.Nakamura, H.Sato, M.Yamamoto, K.Kato, and 
R.L.Fugihon: On the fractal nature of heart rate variability in humans; 
effects of vagal blockade, Regulatory Integrative Comparative 
15) Y.Miyake and J.Tanaka: Mutual-enforcement-based internal control in 
International Conference on Systems, Man, and Cybernetics (SMC'97), 
Orland, USA, 293/298 (1997)
16) Y.Miyake, T.Miyagawa and Y.Tamura: Internal observation and mutual 
adaption in human-robot cooperation, Proc. of 1998 IEEE International 
Conference on Systems, Man, and Cybernetics (SMC'98), SanDiego, 
USA, 3658/3660 (1998)
17) Y.Tamura, Y.Miyake: Mutual-adaptation based cooperative walk system 
in (Japanese), Proc. of 10th SICE Symposium on Decentralized 
18) Y.Miyake and T.Miyagawa: Internal observation and co-generative 
interface, Proc. of 1999 IEEE International Conference on Systems, 
Man, and Cybernetics (SMC'99), Tokyo, Japan, I-229/1-237 (1999)
19) Man-machine interaction as co-generation process (in Japanese), Trans. 
of the Society of Instrument and Control Engineers, 37-11, 1087/1096 
(2001)
20) T.Muto, Y.Miyake: Analysis of the Process of Mutual Interaction between 
Human and Internal Control Model, Proc. of 2000 IEEE International 
Conference on Systems, Man, and Cybernetics (SMC2000), Nashville, 
USA, 769/774 (2000)
21) T.Muto, Y.Miyake: Analysis of co-emergence process on the human-
22) H.Takahashi, Y.Miyake: Co-emergence robot Walk-Mate and its support 
for elderly people (in Japanese), Trans. of the Society of Instrument and 