# 유발전위신호(ERP)를 통한 시각과 촉각 통합작용의 신경생리적 특징 분석

주유미[1](zxc83@snu.ac.kr), 이경민[1,2](lee.kyoungmin@gmail.com)
[1]서울대학교 협동과정 인지과학 전공, [2]서울대학교병원 신경과

# Event-related potentials reveal neural signatures of cross-modal interaction between visual and tactile stimulation

**Yumi Ju[1], MS, OT, & Kyoung-Min Lee[1,2], MD, PhD,**

**Interdisciplinary Program in Cognitive Science[1], Seoul National University, Seoul, Korea**
**& Department of Neurology[2], College of Medicine, Seoul National University, Seoul, Korea**

*[*]Correspondence should be addressed to Ju Yumi (zxc83@snu.ac.kr)*

**Abstract**

**INTRODUCTION** Interaction between temporal events at the millisecond level is important for visual and tactile interaction. **OBJECT** The aim of the present study is to identify any neural signature, as reflected in event-related potentials (ERP), for the integrative processes when the two sensory modalities are stimulated in synchrony as opposed to when they are stimulated separately. **METHOD** The basic strategy was to compare ERP signals obtained with simultaneous visual and tactile stimulation with a linear summation of ERP patterns obtained with each modality stimulated separately. Condition were presented, paired with various stimulus-onset-asynchronies (SOA) ranging from -300 ms (tactile-first) to 300 ms (visual-first), and in trials where only one modality was stimulated alone. **RESULT** A positive deviation was located in observed ERP at C4 electrode (contralateral to the stimulated hand) at 200-400 ms, in comparison to the predicted ERP. The deviation was present at all SOAs other than -300ms (tactile-first) and 300 ms (visual-first). There was also a positive deviation at occipital leads at the 50-ms SOA (visual-first) trials. **DISCUSSION** It suggested that neural signatures of cross-modal integration occur within a limited time-window. The deviations were specifically localized at the contralateral somatosensory and visual cortices, indicating that the integration happens at or before the level of the primary cortices.

## INTRODUCTION

Multisensory integration is the process to gather unimodal sensory information through each sensory system to perceive the object as unitary and stable entity. Especially, visual and tactile integration is early developed in infancy as the way to explore objects surrounding environment of infants (Lewkowicz, 1994). Interaction between visual and tactile communicates each other in neural system in brain and it influences final percept of the objects or events. Parchment-skin illusion is well known as example of illusory perception of tactile and auditory interaction and it explains that auditory signals to brain alters tactile information from rubbing hands(Jousmaki, 1998). Interaction between Temporal constraints in millisecond level is important to determine visual and tactile interaction (Foxe, 2000; Ohara, 2006). Asynchrony of the two different sensory

modalities is not ascertained at the level of perception, but neural interplay for visual and tactile integration according to temporal asynchrony between two sensory resources.

Method for comparing linear summation of each unimodal sensory input with observed simultaneous effect is commonly used to prospect for interaction effect between two modalities (Brett-Green, 2008; Foxe, 2000; Okajima, 1995; Teder-Salejarvi, 2002). The ERP patterns obtained in single-modality stimulation conditions were linearly added to generate a predicted ERP pattern with no interaction occurring. The predicted pattern was then compared with observed ERPs with dual-modality stimulation with the corresponding SOAs.

Mathematical linear manipulation was conducted to observe interaction effect of visuotacile stimulus when applying simultaneously. Extra alpha effect by visuotactile interaction was calculated by difference between linear summation of visual and tactile sensory activities and simultaneous multimodal activities (Interaction effect (α) = Simultaneous (VT) – Summed (V+T)).

## METHODS

### Subjects

12 subjects (3females, mean age 24, age range 20-28), neurologically healthy adults were recruited in Seoul National University and students are paid for participating in this study. They were tested the dominant hand by Edinburgh Dominant handeness questionaire and are all right-hand dominant. Experiments were preceded in quiet and dimly lit room sitting in front of the table which visual and tactile stimuli were set up.

### Stimulus

An on-offset checkerboard for visual stimulus and low-frequency electrical stimulation for tactile stimulus were presented in pair with various stimulus-onset-asynchronies (SOAs). On-offset checkerboards were reversely flickered for 10ms through CRT monitor (resolution 1280x1024, refresh rate 60Hz). Tactile electrical electrodes were placed on the ventral surface of left forearm which is about 1cm proximal toward wrist crease to mainly target the median nerve. Electrical stimulation was provided with intensity range 3-6mA below the threshold of evoking a twitching response. Intensity of electrical stimulation was individually modulated enough to stimulate median nerve and up to the level that the subject still feels comfortable for stimulation. Pulse duration is 400μs and frequency of electrical train is 1 per second (1Hz).

Various stimulus-onset-asynchronies (SOAs) range from -300ms (tactile-first) to 300ms (visual-first), and in trials where only one modality was stimulated alone. Total 9 conditions randomly mixed in order. Total 140 trials for each condition and ERP was conducted through separate 7 runs (total = 9conditions * 140 trials). All 140 trials for each condition are averaged in 900ms epochs including 200ms pre-stimulus period for baseline and grand-average for total 12 subjects was calculated. Short intermission less than 1 minute was placed before starting the next run in order to minimize physical fatigue from visual and tactile stimuli and also neurophysiological adaptation

### Data analysis

The basic strategy was to compare ERP signals obtained with simultaneous visual and tactile stimulation with a linear summation of ERP patterns obtained with each modality stimulated separately. The predicted ERP pattern is calculated by linear summation of only visual evoked potential (VEP) and only somatosensory evoked potentials (SEP). In SOA conditions, for example in tactile stimulus first condition, the VEP data are shifted for each SOA and then are added to tactile ERP data. To verify presence of additional visuo-tactile interaction

between simultaneously presented (observed, VT) condition and Summed (predicted, V+T), differences of two ERPs were statistically compared by using pairwise t-test for group average data for total 12 subjects. Statistically significant differences lasting for 40ms were defined as the difference by neural activities in two conditions according to physiological characteristic of neurons.

The digitized ERP data (sampling rate at 256Hz) were tested by moving window technique to strictly accept evoked potentials which reflect actual neural activities. Every time bin for 40ms which means physiological trait of neural cluster firing were consecutively tested by moving time window (jumping epoch for 20ms) in total time epoch (700ms). At least three sequential time bins which are statistically significant ($p<0.1$) are accepted as actual neural cluster activities, that is, differences of neural activities between two conditions should be last for 80ms at least ($p<0.001$).

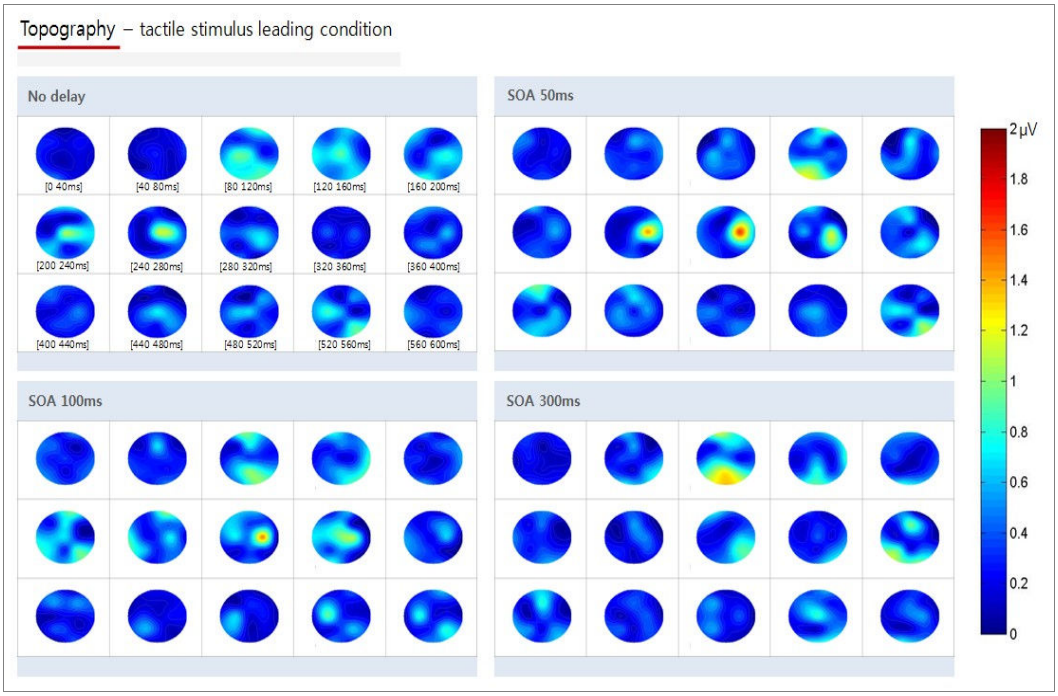
## EEG recording

Evoked Potentials (EPs) were recorded with Ag/AgCl cup electrodes at total 15 cites (Fp1, Fp2, P3, P4, C3, C4, P3, P4, O1, O2, T3, T4, Fz, Cz, Pz) followed by international 10-20 system, and additional reference and ground channels were recorded at forehead and earlobes respectively. Systematic artifacts due to eye movements were rejected by additionally measuring electro-oculograms (EOGs). Impedances were set to below 10kΩ and low band pass filter (30Hz) was applied. The signals were digitized at 256 Hz sampling rate.

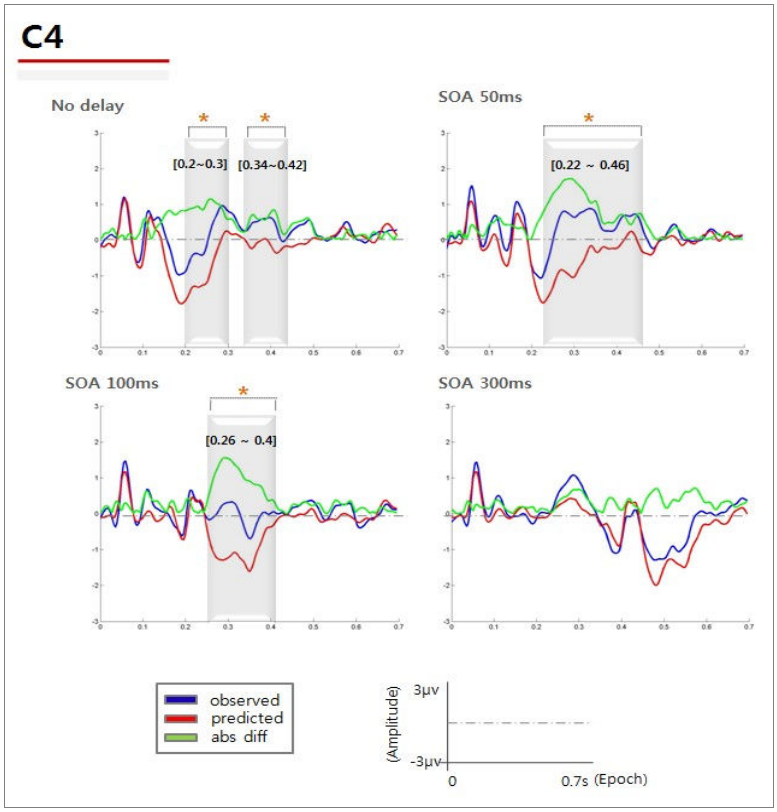
## RESULTS

Main difference between the observed and the predicted pattern was shown in C4 electrode at time epoch 200-280 ms from tactile onset when tactile stimulus is preceding visual event with SOAs (figure 1). Furthermore this difference at C4 which indicates somatosensory area contralateral to the stimulated hand is shown in No-Delay, SOA 50ms, 100ms other than SOA 300ms and the differences in these three conditions are also appeared in time-locking from onset of visual presentation.

Further statistic analysis was conducted with pair-wise t-test and grand-average of ERP for observed, predicted, and absolute difference between two were plotted in figure 2. A positive deviation was located in observed ERP at C4 electrode (contralateral to the stimulated hand) at 200-400 ms after the onset of tactile stimulation, in comparison to the predicted ERP, i.e., the linear summation of ERPs with individual modality stimulation. In No-Delay condition, it shows statistically significant difference between observed and predicted at 200-300ms and 340-420ms ($p<0.001$). In SOA 50-ms, it shows statistically significant difference at 220-460ms ($p<0.001$). In SOA 100-ms, it shows statistically significant difference at 260-40ms ($p<0.001$). The positive deflection at about 200-400ms from visual stimulus onset is consistent over different SOA conditions other than SOA 300-ms. Differences between observed and predicted ERP was not shown when visual stimuli is preceded by tactile stimuli with more than 300ms gap.

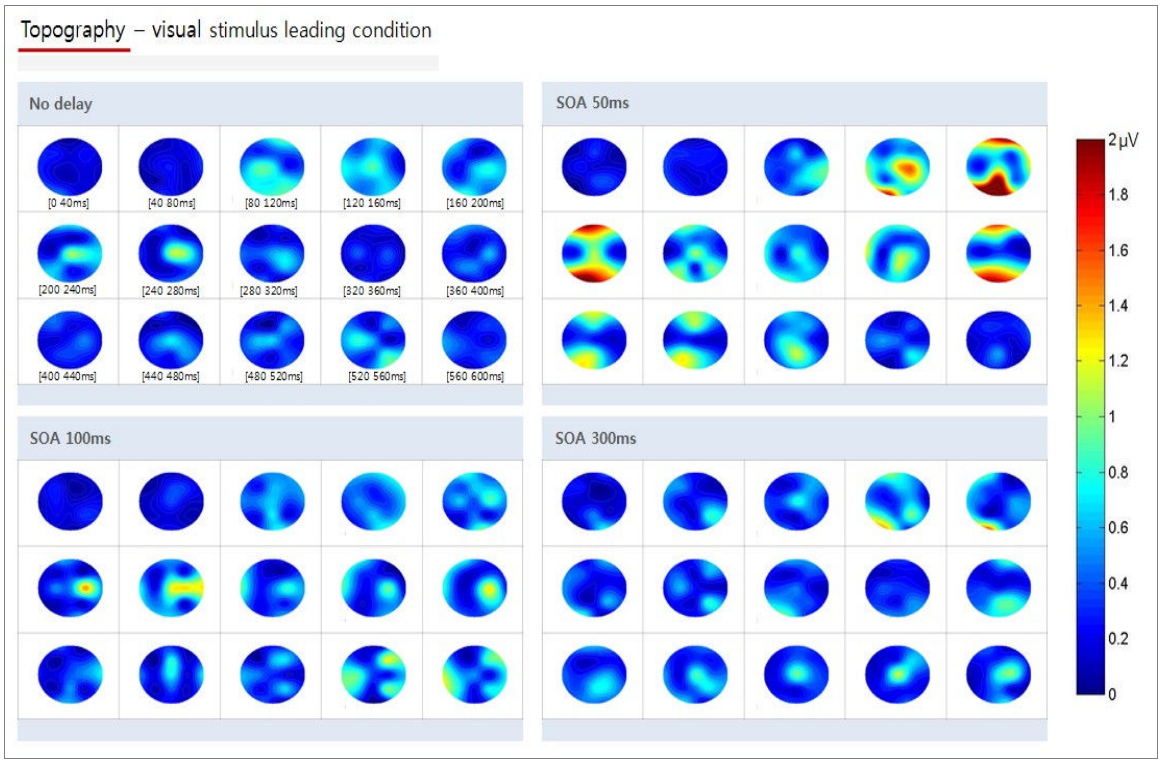



**[Figure 1]** Topography of the absolute difference between the observed(simultaneous) and the predicted(linearly summed) ERPs in conditions which tactile is preceding visual stimulus with different SOAs - ERPs are displayed in 40ms interval (epoch [0 - 600ms]) and the range of voltages shows in color-bar (0-2 μV).




**[Figure 2]** **ERPs plot (C4)** – grand average of observed (simultaneous) ERPs(blue) and of predicted(linearly summed) ERPs(red) when tactile is preceding visual stimulus with SOAs(0, 50, 100, 300ms). The absolute difference (green) between observed ERP and predicted ERP was calculated. Time epochs that show statistically significant difference are marked with the gray columns ($p<0.001$).

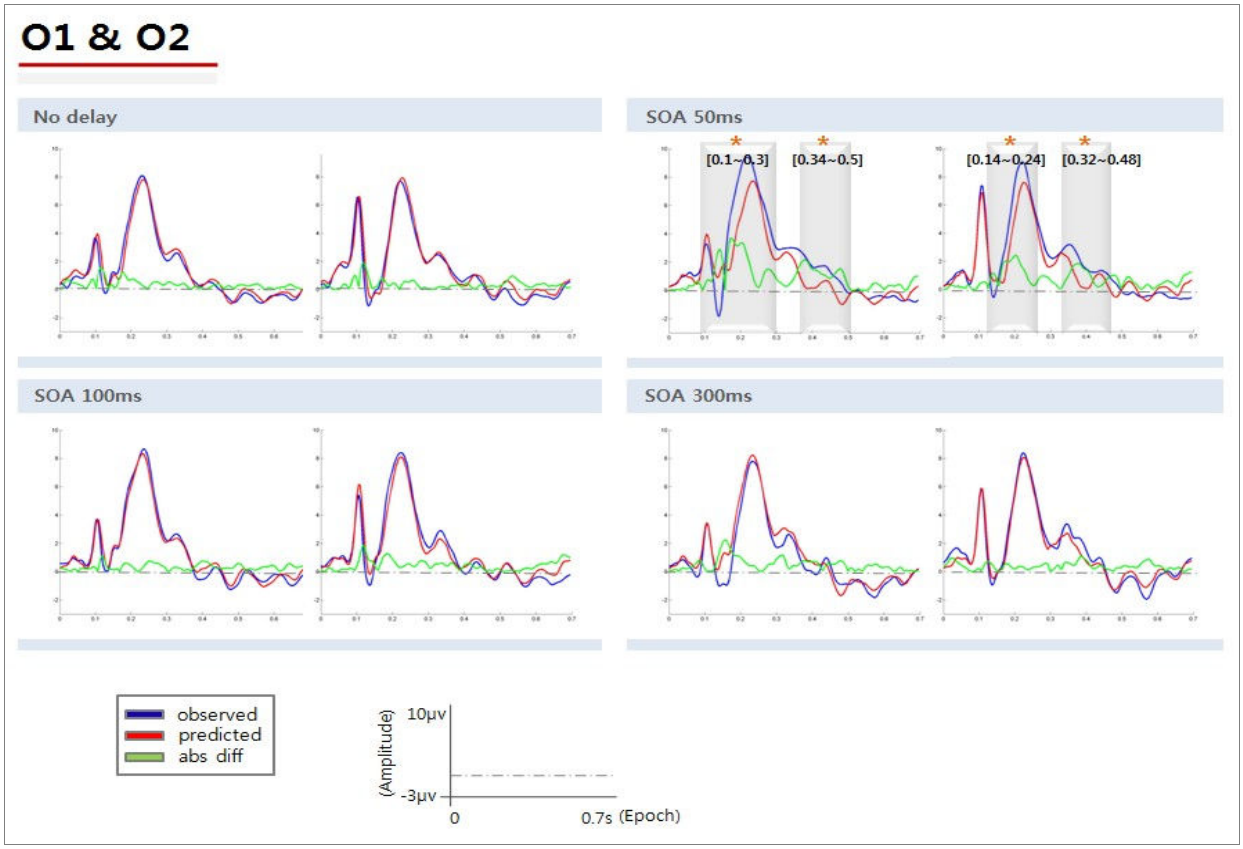
There was also a positive deviation at occipital leads at the 50-ms SOA (visual-first) trials, but occipital deviation was not observable in any other SOA conditions (figure 3). Difference between the observed and the predicted is appeared in 160-240ms at O1 and O2 in topographical map. In pair-wise t-test in same way as tactile first condition, it shows statistically significant difference in 100-300ms, 340-500ms at O1 ($p<0.001$) and in 140-240ms, 320-480ms at O2 ($p<0.001$) (figure 4). P100 and N220 components of VEP are significantly enhanced when tactile stimulus is delivered with SOA 50-ms after visual event onset.




**[Figure 3]** Topography of the absolute difference between the observed (simultaneous) and the predicted (linearly summed) ERPs in conditions which visual is preceding tactile stimulus with different SOAs

## CONCLUSION

This ERP study obviously shows that visual stimulus modulate not only in the visual areas but the primary somatosensory areas when presenting with tactile stimulus. However, visual modulation on the primary somatosensory cortices is limited with temporal constraints, which means that interaction between visual and tactile stimulus no longer occur if two sensory stimuli are delivered with more than 300ms time gap. Visual modulation on somatosensory cortices appeared in about 200-400ms when two sensory stimuli are simultaneously presented within 300ms. It suggested that neural signatures of cross-modal integration occur within a limited time-window. Note that visual modulation on primary tactile areas is not shown when visual stimulus is presented earlier than tactile stimulus. However, it is interesting finding that visually-evoked activities are advantaged by concurrent tactile stimulus with SOA 50-ms at occipital cortices. Main VEP components at bilaterally O1and O2 are enhanced in amplitude. The deviations were specifically localized at the contralateral somatosensory and visual cortices, indicating that the integration happens at or before the level of the primary cortices.




**[Figure 4] ERPs plot (O1&O2)** – grand average of observed (simultaneous) ERPs(blue) and of predicted(linearly summed) ERPs(red) when visual is preceding tactile stimulus with SOAs(0, 50, 100, 300ms). The absolute difference (green) between observed ERP and predicted ERP was calculated. Time epochs that show statistically significant difference are marked with the gray columns ($p<0.001$). The left graph on each box refers to ERPs at O1 and the right is at O2 electrode.

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