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# Event-related potentials to semantic processing of spoken sentences

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## SUMMARY

To elucidate the contextual effects of the terminal words of spoken Japanese sentences, 21 channel Event-related potentials (ERPs) were recorded for right-handed volunteers with bandpass 0.05-30 Hz and the balanced non-cephalic reference. Two-syllable-verbs were used as terminal words, and their durations were controlled in 200 ms. The two types of sentences that have semantically congruent or incongruent endings, were presented auditorily.

N100, N250, N330, P600 components were elicited by incongruent verbs. The contextual effects of N250 were statistically significant in parietal and right temporal sites, and those of N330 were significant in central and right temporal sites. N100 revealed no contextual effects and P600 had those in temporal sites. These results suggest that the processing of contextual effects would occur about 250 ms latency range and include semantic and pre-semantic processes in the perception of spoken sentences.

**Key words**: event-related potentials, semantic process, contextual effect, N400

## I. Introduction

N400 component is regarded as an electrophysiological sign of the contextual effect, and is clearly observed in ERPs by a semantically incongruent ending[1-2]. Individual words in the sentences were presented visually in most of these studies, and the N400 is typically larger over the right than left hemisphere in the visual modality.

Only few studies used spoken languages. The study[3] using a auditory replication of the visual work by Kutas et al, showed N400 (peaking at 456 ms) over frontocentral sites and sustained positive component in the semantically incongruent condition. The auditory N400 showed no significant difference in scalp distributions between the right and left hemisphere. Other study of spoken sentences [4] showed the posterior N400 was more negative over left hemisphere and the onset of contextual effects was as early as 50-100 ms

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over left occipital site.

Recent work in the auditory modality using spoken sentences[5] has demonstrated a negative response (250-270 ms) preceding the N400, called the phonological mismatch negativity. In the study, the initial phoneme of the terminal words in a phoneme mismatch condition were used. However, English word has not so clear syllable boundaries and syllable-based timing patterns[6]. On the other hand, Japanese has relatively clear syllable boundaries, and some advantage in controlling the duration and phoneme of spoken words.

In the present study, we used Japanese two-syllable-verbs with controlled voice duration as terminal words, to elucidate the more precise time course of the contextual effects in spoken language.

## II. Material and Methods

### 1. Subjects

13 healthy right-handed volunteers participated in this study. All subjects were native speakers of Japanese and had no history of audiological, neurological disorders.

### 2. Experimental conditions and stimuli

The two conditions of Japanese sentences (40 per condition) were used, in which the terminal two-syllable-verb is semantically congruent or incongruent. Examples of the types of sentences follow : congruent verb ; WATASHIWA / KIMINI / TEGAMIWO / KAKU = I/write/a letter/to you in English : incongruent verb ; WATASHIWA/KIMINI/TEGAMIWO/NOMU = I/drink/a letter/to you/in English (Fig. 1). And these sentences were selected as follow : 100 university students were presented with a list of 80 sentences and were asked to specify the congruent two-syllable-verb of each sentence. When the same verb was chosen by more 80% students, the verb was applied to the congruent condition. The experimenters made the incongruent sentences exchanged the verbs from selected 40 congruent sentences. The incongruent verbs didn't share the initial phoneme with the original congruent verbs.

The 80 sentences used in the experiment were recorded using a trained male voice, digitized at 11.025 kHz. Pulses were placed on a separate channel at the time of the onset

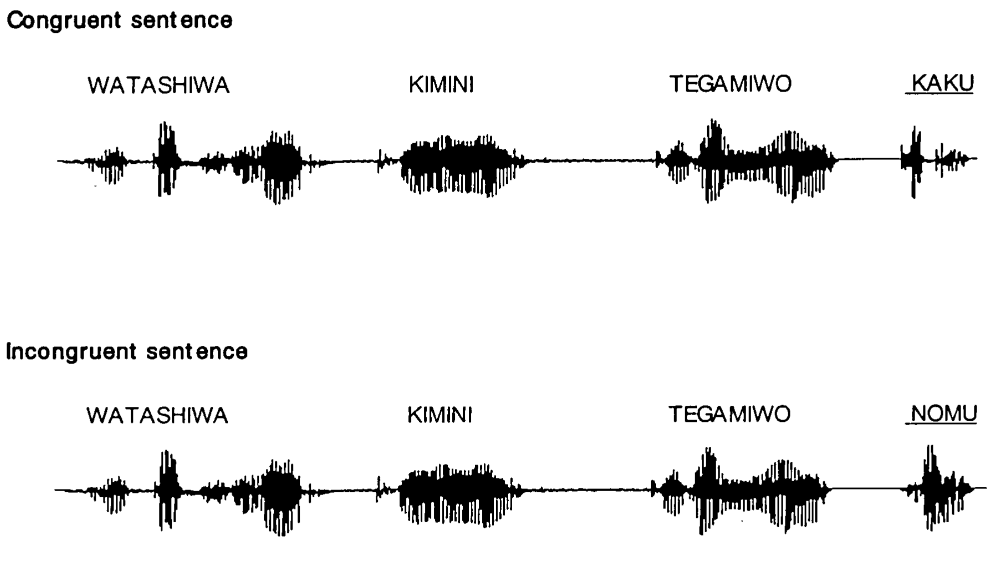


Fig 1
Examples of sentences in the present study. The durations of all terminal verbs were regurated in 200 ms.The incongruent verbs shared no initial phoneme with the original congruent verbs.

of the terminal word of each sentence. The durations of all terminal verbs were regulated in 200 ms in a personal computer. The sentences and pulses were recorded onto a cassette for use.

**3. Procedure**

The subjects were seated in a comfortable chair with their eyes open and fixated, asked to listen the sentences carefully and decide whether the meaning was congruent or not, and extend the index finger if congruent and flex if incongruent. The words were presented at approximately 70 dB SPL peak intensity. The finger movement was monitored by the acceleration meter and the accuracy of their judgment was assessed.

**4. EEG Recording**

21 channel ERPs were recorded according to International 10-20 system using the balanced non-cephalic electrodes. Vertical and horizontal EOG was monitored to reject artifacts with electrodes placed supraorbitally and over the outer canthus of the right eye. An electrode attached to the forehead served as ground. The band-pass filter was set from 0.05 to 30 Hz, and signals were sampled at 500 Hz during -100 and 800 ms (Biotop 6R12, NEC-San-ei, Japan).

**5. Data analysis**

Peak amplitude and latency measures were made for each electrode on the average wave forms of each subject. The N330 was scored as the most negative point in the 300-500 ms latency range. A negative response which preceded the N330 was scored as the most negative point between 200 ms and the N330 and was labeled the N250. N100 was scored as the most negative point in the 0-150 ms latency range. Late positive component (LPC) was scored as the most positive point between the N330 and 800 ms.

Amplitude was calculated as the voltage difference between the mean activity for the 100 ms period before stimulus onset and the point scored within a specified latency range. Latency was calculated as the time from the terminal word onset to the point.

Repeated measures analyses of variance (ANOVAs) were performed separately for ERP data of the midline electrodes (Fpz, Fz, Cz, Pz, Oz), parasagittal electrodes (Fp1/2, F3/4, C3/4, P3/4, O1/2) and temporal electrodes (F7/8, T3/4, T5/6), to analyze scalp distribution effects. For midline electrodes had 2 factors; condition (congruent, incongruent) and electrode site (5 levels). Parasagittal and temporal electrodes were analyzed for 3 factors; condition, hemisphere (right, left) and anterior/posterior (parasagittal electrodes had 5 levels and temporal electrodes had 3 levels.)

## III. Results

**1. Accuracy of judgments**

The mean of error responses in this experiment was only 2.67 (SD=2.24) in all 80 trials. Most of judgments by subjects were appropriate in this study. No difference was observed between congruent and incongruent conditions.

**2. Grand mean ERPs**

As can be seen in Fig. 2, ERP grand average waveforms showed an increased negativity with two different peaks in the incongruent condition in the latency range of 200-400 ms. This negativity had a predominantly right centroparietal distribution. N100 with frontocentral distribution and LPC with centroparietal distribution were observed in both conditions with some variances of amplitude and latency.

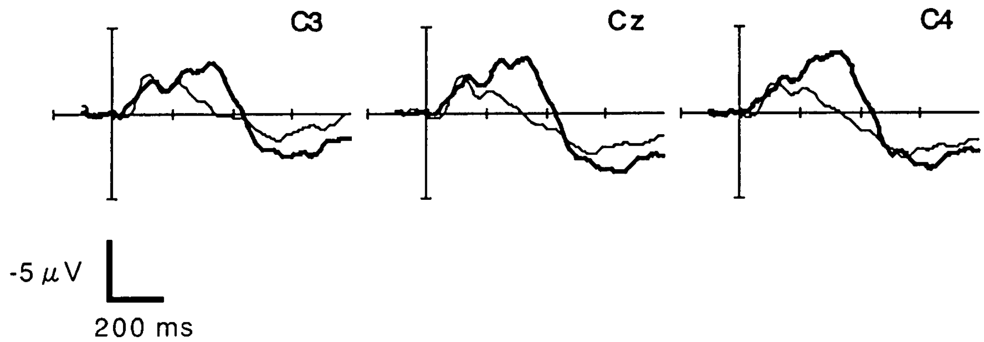


Fig 2
Grand mean averages at C3,Cz,C4, after the onset of terminal words for the semantically congruent (thin line) and incongruent verbs (thick line). The waveforms of the incongruent endings produced increasing negativity with two peaks, while the congruent endings produced small N200.

| | | *P*-value | | | |
|---|---|---|---|---|---|
| Electrodes | Interaction | N100 | N250 | N330 | P600 |
| Midline | C×Ant/post | n.s. | 0.025 | 0.001 | n.s. |
| Prasagittal | C×H×Ant/post | n.s. | 0.046 | 0.003 | n.s. |
| Temporal | C×H×Ant/post | n.s. | 0.002 | n.s. | n.s. |

Table 1
Statistical results of peak amplitudes. N100, N250, N330, P600 component was analyzed respectively in midline, parasagittal and temporal electrode sites. Remarkable main effects of condition and interaction were observed over each scalp site in N250 and N330. C=condition ; H=hemisphere ; A/P=anterior/posterior (electrode site factor from anterior to posterior direction) ; $P>0.05$ was expressed as n.s.

**3. Amplitude**

• N100

ANOVAs of N100 revealed no condition effects in all electrode sites (Table 1). Midline sites showed a significant main effect of anterior/posterior ($F$ (4, 48) = 13.636, $P<0.0005$, $\varepsilon=0.5178$) and Cz (M=4.31μV) was larger than other sites. Parasagittal sites showed a hemisphere × anterior / posterior interaction ($F$ (4,48) = 8.425, $P=0.002$, $\varepsilon=0.4556$) and C3 (M=4.63μV) was larger than other sites.

• N250

As can be seen in Table. 1, ANOVAs of N250 confirmed that there was a condition× site interaction in midline sites ($F$ (4, 48) = 12.466, $P=0.025$, $\varepsilon=0.4114$) and Pz in the incongruent condition (7.145μV) was larger than other sites. Parasagittal electrodes showed a condition × hemisphere × anterior / posterior interaction ($F$ (4, 48) = 3.609, $P=0.046$, $\varepsilon=0.4687$) and P4 in the incongruent condition (7.414 μV) was larger than other sites. Temporal sites also showed a condition ×hemisphere× anterior/posterior interaction ($F$ (4, 48) = 8.882, $P=0.002$, $\varepsilon=0.9265$) and T4 (6.800 μV) was larger than other sites. These results indicated that condition effects in N250 were significantly recognized in parietal and right temporal sites.

• N330

From analysis of N330 of midline electrodes, a significant condition × anterior ⁄ posterior interaction was observed ($F$ (4, 48) = 10.336, $P$=0.001, $\varepsilon$=0.5142) and Cz in the incongruent condition (7.37 $\mu$V) was larger than other sites (Table. 1, 2). Parasagittal electrodes also showed a condition × hemisphere × anterior ⁄ posterior interaction ($F$ (4, 48) = 20.060, $P$=0.003, $\varepsilon$ =0.5273) and C6 in the incongruent condition was larger than other electrodes. Temporal electrodes showed a condition × hemisphere interaction ($F$ (1, 12)=5.416, $P$=0.038) and no anterior ⁄ posterior effects. Right temporal sites (M = 6.52 $\mu$V) were larger than left temporal sites. These results indicated that condition effects in N330 were significant in central and right temporal sites.

• LPC

Analysis of P600 revealed a main effect of anterior ⁄ posterior ($F$ (4, 48)=9.551, $P$=0.001, $\varepsilon$=0.4822) and no condition effects in the midline electrodes. Parasagittal sites had a hemisphere × anterior ⁄ posterior interaction ($F$ (4, 48) = 7.266, $P$ = 0.002, $\varepsilon$ = 0.5740). Temporal sites had a condition × anterior ⁄ posterior interaction ($F$ (2, 24) = 5.199, $P$ = 0.018, $\varepsilon$=0.8731) and T7⁄8 in the incongruent condition (M = 5.03) was larger than other sites. These results indicated that condition effects of LPC were recognized in temporal sites.

### 4. Latency

Analysis of N100 confirmed there were no condition effects in all electrode sites. Midline sites had a main effect of anterior ⁄ posterior ($F$ (4, 48) = 3.818, $P$ = 0.046, $\varepsilon$ = 0.4145) and Oz (90.00 ms) was the earliest and Fz (122.77 ms) was the latest. Parasagittal sites had main effects of hemisphere ($F$ (1, 12) = 9.590, $P$ = 0.009) and anterior ⁄ posterior ($F$ (4, 48) = 5.001, $P$ = 0.005, $\varepsilon$ = 0.7602). Right sites (M = 108.42 ms) were earlier than left sites and, O1⁄2 (M = 87.50 ms) was the earliest and F1⁄2 (M = 123.04 ms) was the latest. Temporal sites had only a main effect of hemisphere ($F$ (1, 12)=9.181, $P$=0.010) and left sites (M=101.97 ms) were earlier than right sites.

Analysis of N250 revealed only a main effect of condition in temporal sites ($F$ (1, 12) = 12.766, $P$ = 0.004) and the incongruent condition (M=254.59 ms) was later than the congruent condition (M = 230.41). N330 had a hemisphere × anterior ⁄ posterior interaction in parasagittal sites ($F$ (4, 48) = 8.356, $P$ = 0.001, $\varepsilon$=0.5560) and C4 (M = 327.12) was the earliest.

LPC also had a hemisphere × anterior ⁄ posterior interaction in parasagittal sites ($F$ (4, 48) =4.072, $P$=0.023, $\varepsilon$ =0.5840) and O2 (M= 565.62) was the earliest.

## Ⅳ. Discussion

Using the terminal words with controlled 200 ms duration in spoken sentences, N100, N250, N330 and P600 components were elicited by the incongruent condition.

The statistical analyses of N100 revealed no condition effects and P1-N1-P2 components were not so clear. The results were consist with previous studies. These components have been reported to be attenuated at shorter interstimulus intervals and to be connected to physical parameters of the stimulus [7,8]. Our study had only 200 ms from pre-terminal words to the onset of terminal words and mean intensity of stimuli were also regulated. Moreover, a recent MEG study using tone and vowel, showed that the amplitude and dipole strength of N1 appeared no statistically different, while these parameters of sustained magnetic field after N1m were larger for vowel signals than for the tone signals [9].

N250 component was observed in this study (mean latency of the congruent condition was 235.1 ms). The off-response which is elicited by the termination of the stimulus generally occurs 100 ms after termination[10]. However, it could not explain the significant condition effects in parietal and right temporal sites on amplitude and latency. The auditory study, using nonspeech sound and spoken words pairs, showed that contextual effects for the two types of stimuli had a different pattern of laterality, however, both began at nearly the same time, approximately 200 ms poststimulus onset. This 200-300 ms onset range for the ERP auditory priming effect was confirmed by other studies, despite their long word duration[11]. Connolly et al.[12] have demonstrated the phonological mismatch negativity (PMN) in 200-300 ms latency range with frontocentral scalp distribution. They insisted that the PMN was elicited by sentences with equal probability condition, and reflected a process sensitive to the unexpectedness of the initial phoneme of a word. The N250 component in the present study might reflect phonological process of spoken words, because we also used equal probability condition and controlled not only semantic but also initial phoneme factors in terminal words.

The negative polarity, its latency, centroparietal distributions and the incongruent and congruent conditions in this study suggest that the N330 would be similar to the N400 component, which has been reported to be sensitive to semantic priming [1,2,13-15]. However, its lateral distribution was different from previous studies. N330 in this study showed the condition effects in mid-central, right parasagittal and temporal sites, while most studies reported auditory N400 show no statistically significant difference in scalp distribution between over right and left sites [3,5,16]. On the other hand, Holcomb et al [11] showed N400 was more negative over the left hemisphere in the temporo-parietal electrode sites, using spoken sentences. Although the present study does not have sufficient evidence for lateral asymmetry of contextual effects, prosodic factors might reflect the scalp distributions[17]. In spoken sentences, words have prosodic factors, which refer to the rhythmic patterns both within words (lexical prosody) and across the words of an utterance (metrical prosody)[6]. The studies using dichotic lisening in normal or brain damaged subjects have pointed to a specialized role in auditory functions, complex pitch information and prosody, for the right hemisphere[18-20].

In the future, further study shoud be reqired under the conditions which not only semantic but also phonological and other auditory factors are regulated. However, the present study with controlled word duration could clarify the time course as early as 200-400 ms latency range in the spoken sentences, and the N250 and N330 components would reflect the pre-semantic and semantic process of contextual effects.


## 要　旨

音声言語の経時的な処理過程の機構については，刺激条件の設定の困難さから未だ不明の点が多い。本研究では，音声言語の持続時間を統制した刺激条件を開発し，事象関連電位の解析からその処理過程を検討した。2音節の動詞を配した正常文と逸脱文の弁別課題を健常成人に施行し，21ch の平均加算波形を平衡頭部外基準電極にて記録した。その結果，逸脱文では，N100，N250，N330，P600が記録された。分散分析の結果から，逸脱文の音韻処理あるいは意味処理には音声刺激提示後約250ms から左右両半球の神経活動が関与することが示唆された。正常文の処理過程では，プライミング効果により言語処理が効率化されていることが推察された。


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