Hemispheric Laterality in Contextual Recognition

Ichiro SHIMOYAMA, Toshihiko ITO, Tadahiko SHIBATA,
Dilshat ABLA, and Yoshio NAKAJIMA

Department of Physiology, School of Medicine, Chiba University, Chiba, 260–8670 Japan

Abstract: Hemispheric dominance in contextual recognition is now under discussion. Auditory event-related potentials (ERPs) with a contextual decision task were recorded to study hemispheric dominance by using the wave energy and amplitudes of N400 for eight native volunteers. Two types of 80 sentences with four clauses were used as the structure: [subject]+[object or complement]+[object]+[two-syllable verb]. One type was congruent and the other deviated at the terminal clause as an incongruent sentence. Twenty-one channel ERPs were triggered at the verbs and recorded during –200 and 1,000 ms, with a noncephalic reference from 0.05 to 30 Hz. The wave energy was calculated as mean square potentials and was normalized

with the background activity (pretrigger 200 ms). The amplitudes of N400 showed significant differences between the incongruent and congruent sentences, but the hemispheric dominance for the amplitudes of N400 was not significant between the incongruent and congruent sentences. Reaction times with the index finger to respond to the deviated verbs were 470.0 (mean)±42.5 (SD) ms. The maximum normalized wave energy within the mean reaction time showed significant differences between the incongruent and congruent sentences, and the left hemispheric energy was shown to be significantly higher than the right one. [Japanese Journal of Physiology, 48, 493–497, 1998]

Key words: auditory event-related potentials, background activity, contextual recognition, N400, normalized wave energy.

N400 was reported for the incongruent sentences [1], and the recognition potentials were recorded from 200 to 250 ms for words, pictures, and faces, but not for nonmeaningful control images [2]. They are good noninvasive methods to study human contextual recognition. A certain peak amplitude or peak latency of the event-related potentials (ERPs) varied among subjects even for one task. Moreover, background activities varied among the recording sites even per subject. The fluctuations are one obstacle to study ERPs. Which peaks, negative or positive, could not be decided as responsible in the recognition of spoken sentences. The negative and positive potentials were both hypothesized as responsible for contextual recognition, and the physical wave energy could globally treat both potentials: thus the wave energy was applied to the ERPs for contextual recognition. It was normalized with the background activity to improve the fluctuation, and the hemispheric dominance was then studied in contextual recognition, comparing it with the amplitudes of N400.

METHODS

Subjects. Eight native volunteers, aged 35.1 (mean)±9.1 (SD) years, participated in this study. None had any history of neurological disease, and hearing was normal. All subjects were right-handed by self-report, and the laterality quotient of the Edinburgh inventory [3] was 92.8 (mean)±6.6 (SD)%.

Tasks. Each subject was asked to listen to Japanese sentences and to discriminate their congruity. Each sentence comprised four clauses: (1) subject, (2) object or complement, (3) object, (4) two-syllable verb. Two types each of 80 sentences were used; one type was deviated at the last clause as an incongruent

Received on August 10, 1998; accepted on October 28, 1998

Correspondence should be addressed to: Ichiro Shimoyama, Department of Physiology, School of Medicine, Chiba University, Chiba, 260–8670 Japan. Tel: +81–43–226–2027, Fax: +81–43–226–2028, E-mail: ichiro@med.m.chiba-u.ac.jp

sentence, and the other was congruent. For example, “WATASHIHA/KIMINI/TEGAMIWO/NOMU” in Japanese was “I drink a letter to you” in English as an incongruent sentence, and “WATASHIHA/KIMINI/TEGAMIWO/KAKU” was “I write a letter to you” as a congruent sentence. The sentences were spoken by a male, and the two-syllable verbs were edited to be played back for 0.2 s; trigger signals for ERPs were set at the same times as for the verbs. The sentences were recorded by a tape recorder at random, with interstimulus-intervals of 7 to 10 s at random. The sentences were presented at 65 to 75 dB (sound pressure level) with a loudspeaker, 1 m in front of the subject.

Recordings. Twenty-one channel ERPs were recorded following the International 10–20 system with the balanced noncephalic reference [4], and vertical electrooculography was monitored for artifact rejections. The signals were sampled at 500 Hz from –200 to 1,000 ms with a band-pass filter of 0.05 to 30 Hz. On different days, the reaction times (RTs) were measured; the subjects, listening to the tape recorder, were asked to hit a key for any verbs (simple RTs) and for the deviated verbs (complex RTs).

Data analysis. A zero level was defined as the mean potential of the pretrigger 200 ms for each recording site. For amplitude analysis, N400 was defined as a maximum negative potential of 300 to 500 ms for the incongruent sentences, and the amplitude at the same latency as that for the incongruent sentences was defined for the congruent sentences. The wave energy for ERPs was calculated as the mean square potentials [5], i.e.,

$$\text{Wave energy } (E) = \frac{1}{T} \int_0^T f(t)^2 dt,$$

where $f(t)$, wave signal; T , analyzing interval. The wave energy was normalized in dB with the pretrigger energy, i.e.,

$$\text{Normalized wave energy} = 10 \times \log_{10} \left(\frac{E_{\text{posttrigger}}}{E_{\text{pretrigger}}} \right).$$

The intervals to analyze were 2 to 1,000 ms in steps of 2 ms.

Statistical analysis. The values are presented as mean $\pm$ SD. The one-way repeated measures analysis of variances (ANOVA) was applied to test the amplitudes of N400 and the normalized wave energy for two tasks (incongruent and congruent sentences), the locations (21 recording sites for the tasks and 16 sites without five sagittal sites for the laterality), and the laterality (right and left). The paired t -test was applied to test RTs.

RESULTS

The grand average of ERPs for the incongruent sentences showed two negative peaks, 136 and 346 ms, and a positive peak at 668 ms, and for the congruent sentences a negative peak at 118 ms and a positive peak at 622 ms, measured at Cz. N400 for the incongruent sentences showed remarkable differences from the congruent sentences (Fig. 1). Table 1 showed the amplitudes of N400, which showed significant differences for the tasks ($F(1,7)=8.31$, $p<0.05$); the trials interaction of the tasks by location was significant ($F(1,20)=4.21$, $p<0.0001$). No significant difference was noted for the laterality.

Figure 2 shows an example of the normalized wave energy and the mean RTs for one subject. The maximum normalized wave energy showed at the latency of 384.0 ± 27.6 ms for the incongruent sentences. The simple RTs were 183.5 ± 37.0 ms, and the complex RTs were 450.0 ± 83.4 ms for the incongruent sentences.

For all subjects, the simple RTs were 195.9 ± 30.4 ms, and the complex RTs were 470.0 ± 42.5 ms for the incongruent sentences; a significant difference was noted between the RTs ($t=14.3$, $p<0.0001$). To decide the congruity completed within the complex RTs thereafter, the maximum normalized wave energy within 470 ms was analyzed. Table 2 showed the max-

Table 1. Peak amplitude of N400 (μ V).

Site	Incongruent sentences		Congruent sentences	
	Mean $\pm$ SD		Mean $\pm$ SD	
Fp1	–6.4	4.1	–1.8	4.2
Fp2	–8.8	5.6	–2.4	3.2
F3	–11.0	5.0	–9.4	11.2
F4	–10.2	6.2	–8.9	9.3
C3	–12.8	5.8	–9.7	11.0
C4	–12.4	5.8	–7.6	9.1
P3	–12.8	8.6	–7.1	10.2
P4	–14.1	10.9	–8.6	8.9
O1	–14.3	12.6	–0.7	11.6
O2	–12.8	7.1	–4.6	10.9
F7	–10.1	5.2	–9.1	7.1
F8	–10.6	9.2	–4.4	5.6
T3	–14.2	6.8	–7.3	8.4
T4	–14.8	12.2	–4.8	5.9
T5	–15.6	11.5	–1.1	9.4
T6	–14.9	8.5	–5.4	9.8
Fpz	–6.4	6.8	–2.9	2.9
Fz	–11.0	6.7	–10.3	10.8
Cz	–12.9	6.0	–9.6	8.6
Pz	–12.3	7.8	–9.3	8.9
Oz	–13.5	7.0	–4.0	11.2

Fig. 1. Grand average ERPs. Asterisks show N400 for the incongruent sentences.

Table 2. Normalized wave energy (dB).

Site	Incongruent sentences		Congruent sentences	
	Mean±SD		Mean±SD	
Fp1	22.8	4.2	18.0	4.9
Fp2	10.7	4.7	6.0	4.9
F3	12.7	4.1	8.7	3.4
F4	13.6	1.7	8.6	4.1
C3	14.5	3.2	10.4	3.8
C4	14.7	4.0	9.1	4.4
P3	14.1	4.3	10.7	3.7
P4	15.0	4.7	9.1	3.8
O1	12.6	3.8	10.1	3.7
O2	12.1	3.7	9.7	2.9
F7	11.4	4.0	7.5	3.2
F8	11.7	1.8	10.6	4.1
T3	12.1	2.1	9.1	2.8
T4	12.4	3.2	8.1	3.8
T5	13.0	3.1	11.4	4.7
T6	13.4	3.9	9.7	5.1
Fpz	13.0	3.5	8.2	5.2
Fz	13.7	3.6	8.6	3.2
Cz	15.2	3.7	9.2	4.0
Pz	14.0	4.3	9.7	3.4
Oz	12.7	3.5	9.5	3.4

imum normalized wave energy within 470 ms; significant differences for the tasks were evident ($F(1,7)=74.15$, $p<0.0001$). For the laterality, no significant differences were noted for the incongruent sentences, but significant differences were noted for the congruent sentences ($F(1,7)=9.76$, $p<0.05$).

DISCUSSION

Human brain function has been studied by many methods: positron emission tomography (PET), functional magnetic resonance imaging (f-MRI), magnetoencephalography (MEG), and electroencephalography (EEG). MEG and EEG are better in temporal resolution than PET and f-MRI are, and contextual recognition might be transient in usual behavior; therefore MEG and EEG are better noninvasive methods than PET and f-MRI are. MEG is better in spatial resolution than EEG is, the temporal resolution of EEG and MEG is equal; and EEG and MEG might be complementary to each other. The peak amplitudes or latencies have been discussed for contextual recognition, but divergent results have been reported. The negative [1,6] or positive [2,7,8] peaks were reported to be responsible in contextual recognition, and nega-

Fig. 2. Normalized wave energy for 21 recording sites of one subject. Vertical dashed lines show mean reaction times: "S" for simple reaction and "C" for complex reaction.

tive potentials have been responsible in the auditory semantic process [6,9–11]. Rudell [2] and Lovrich *et al.* [7] have reported the positive potentials for the visual semantic process. The interhemispheric dominance in contextual recognition is now under discussion; Kutas and Hillyard [12] and McCallum *et al.* [13] have reported that the right middle temporal area showed more amplitude than the left one did, but Holcomb and Neville [14] have reported that the left side showed slightly more negative. All their findings have been statistically significant. In the auditory semantic process, Karniski *et al.* [6] have reported that the left posterior temporal area showed a significant difference between the congruent and incongruent effects; however, they did not discuss which potential was dominant.

In this study with the wave energy, the left hemisphere showed significantly higher energy than the right one did for the congruent sentences but not for the incongruent sentences. At present, we could not explain the reason why the hemispheric dominance for the incongruent sentences was insignificant. In the semantic process, Wernicke's area is surely activating for both types of sentences, but in the contextual recognition, the left hemisphere may be suggested to have more electrical activation than the right one for the congruent sentences.

Global field power (GFP) [15] is one method that could completely analyze multiple waveforms; however, GFP can analyze waveforms as a single waveform only in temporal domain, not in spatial domain. The wave energy could analyze waveforms by using negative and positive potentials globally, and, the wave energy could analyze them in both temporal and

spatial domains. No study has been reported for ERPs with the wave energy; therefore the analyzing method was tested and introduced. The amplitudes of N400 could statistically show no hemispheric dominance; however, the left hemispheric normalized wave energy was significantly higher than the right one. Both negative and positive potentials were globally and accumulatively treated as the wave energy, and the wave energy was normalized with the background activity. Therefore the hemispheric dominance was significant in the auditory contextual recognition.

In conclusion, the maximum normalized wave energy in auditory contextual recognition showed significant differences between the incongruent and congruent sentences, and the left hemispheric energy showed a much higher difference than the right one did. This method will be applied not only for ERPs, but also for other evoked potentials.

The authors thank Prof. H. Miyano, Department of Cognitive and Information Sciences, Faculty of Letters, Chiba University, for the statistical analyses, and Prof. Y. Okamoto, Department of Electric Engineering, Chiba Institute of Technology, for useful suggestions.

REFERENCES

1. Kutas M and Hillyard SA: Reading senseless sentences: brain potentials reflect semantic incongruity. *Science* 207: 203–205, 1980
2. Rudell AP: The recognition potential contrasted with the P300. *Int J Neurosci* 60: 85–111, 1991
3. Oldfield RC: The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia* 9: 97–113, 1971
4. Stephenson WA and Gibbs FA: A balanced non-cephalic reference electrode. *Electroencephalogr Clin Neurophysiol* 3: 237–240, 1951
5. Papoulis A: *Probability, Random Variables, and Stochastic Processes*, McGraw-Hill, New York, pp 301–308, 1984
6. Karniski W, Vanderploeg R, and Lease L: "Virtual N400" and slow wave topography to auditory sentence incongruity. *Brain Language* 44: 58–79, 1993
7. Lovrich D, Novick B, and Vaughan G: Topographic analysis of auditory event-related potentials associated with acoustic and semantic processing. *Electroencephalogr Clin Neurophysiol* 71: 40–54, 1988
8. Wu X and Wang WW: Latency of P3 in semantic categorization of Chinese characters: preliminary reports. *Clin Electroencephalogr* 24: 31–36, 1993
9. McCallum WC, Farmer SF, and Pocock PV: The effects of physical and semantic incongruities on auditory event-related potentials. *Electroencephalogr Clin Neurophysiol* 13: 165–172, 1984
10. Connolly JF, Phillips NA, Stewart SH, and Brake WG: Event-related potential sensitivity to acoustic and semantic properties of terminal words in sentences. *Brain Language* 43: 1–18, 1992

11. Bentin S, Kutas M, and Hillyard SA: Electrophysiological evidence for task effects on semantic priming in auditory word processing. *Psychophysiology* 30: 161–169, 1993
12. Kutas M and Hillyard SA: Electrophysiological evidence for task effects on semantic priming in auditory word processing. *Neuropsychologia* 20: 579–590, 1982
13. McCallum WC, Farmer SF, and Pocock PV: The effects of physical and semantic incongruities on auditory event-related potentials. *Electroencephalogr Clin Neurophysiol* 59: 477–488, 1984
14. Holcomb PJ and Neville HJ: Auditory and visual semantic priming in lexical decision: A comparison using event-related brain potentials. *Lang Cogn Process* 5: 281–312, 1990
15. Lehmann D: Human scalp EEG fields: evoked, alpha, sleep and spike-wave patterns. *In: Synchronization of EEG Activity in Epilepsies*, ed. Petsche HH and Brazier MAB, Springer, Wien, pp 307–325, 1972