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SELECTIVE ATTENTIONAL FUNCTIONING AS REFLECTED IN ERPS DURING SYLLABLE DISCRIMINATION TASKS (I)

An Introduction to the Method and Results for Normal Control Subjects *

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Summary

ERPs were recorded at Cz, T3 and T4 in 20 healthy subjects during syllable discrimination tasks. Subjects were required to mentally count thetotal number of particular targets among 4 syllables presented to one ear, ignoring stimuli in the other ear. Stimuli were presented monaurally, but with a very short ISI; thus, these tasks were similar to dichotic listening taks. Amplitudes of N100 as well as P200 varied according to the allocation of attention between the two channels. Amplitudes of late positive components proved to be largest upon detection of the targets. The above results are a replication of findings by Hink et al. In addition, Kimura's hypothesis for dichotic listening was supported by the result that "cross-over" phenomena were observed in the amplitudes and latencies of N100 and P200 between T3 and T4. Furthermore, it was suggested that the left hemisperic dominance for verbal tasks is particularly obvious at the stage of stimulus evaluation.

I. Introduction

Event-Related Potentials (ERPs) are frequently utilized as physiological indexes of human perception, cognition and behavior. Hink et al.1), based on the hypothesis of hierarchical levels of selection2), showed how syllable discrimination tasks were capable of distinguishing the brain wave correlates of between-channel selections based on pitch and ear delivery from the correlates of within-channel selection based on phonetic cues. From their results that the N100 component was enhanced for all stimuli in the attended ear, with the P300 component being enhanced only for target stimuli in that ear, Hink et al. concluded that channel selective attention corresponded to the N100 component, while target detection corresponded to the P300 component. Based on Broadbent's information processing model3-4), Hillyard et al.2) suggested that the N100 amplitude was an index of the early stage of selective attention, termed 'stimulus set', and that the processing events leading up to the P300 wave were akin to Broadbent's 'response set' mode of selective attention.

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In this study, ERPs were recorded during syllable discrimination tasks similar to those employed by Hink et al. The purpose of this study was, firstly, to replicate Hink et al.'s results and to examine the ERP correlates of psychological processes, specifically selective attentional functioning. Secondly, we intended to investigate hemispheric specialization in verbal tasks, as well as sex differences in hemispheric functioning, in physiological terms. Thirdly, we hoped to obtain physiological evidence for the hypothesis that ipsilateral volleys are inhibited during dichotic listening.

II. Subjects

Twenty normal adults (10 males and 10 females; ages 20-38, mean 29.1 years) participated in this study. All of the subjects were right handed, free from any hearing dis-ability, and had no history of neurological or psychiatric disorders. The mean of their number of years of education was 16.5 years.

III. Method

ERPs were recorded during syllable discrimination tasks similar to those employed by Hink et al. Four different CV syllables by a male voice were presented to one ear, with the same four syllables by a female voice being presented to the other ear, through headphones monaurally. Subjects were required to attend to one ear, counting the total number of a particular syllable ('target syllable') in each run.

III-1. Auditory stimuli

Four CV syllables (/ba/, /da/, /ga/, /za/) were recorded separately by a male and a female speaker. After being passed through a 4 KHz high-cut filter (-48dB/oct.), these recordings were digitized at a sampling frequency of 8 KHz and stored in a mini-computer (DEC, LSI-11/2). All eight stimuli were adjusted in shape to a duration of 150 ms. After being passed through the 4 KHz high-cut filter again, eight stimuli were D/A converted and amplified by means of an audio preamplifier (TEAC, AR740). The eight stimuli were then delivered to the subjects through stereo-headphones at an intensity of approximately 60 dBSL. The presentation of the eight stimuli was randomized, with an equal a priori probability of 0.125. Syllables prodeced by the male voice were presented to one channel of the stereo-headphones, with those by the female voice being presented to the other channel with equal frequency. The interstimulus intervals (ISIs) ranged between 800-1000 ms following the Fortran Library Function 'RAN'.

III-2. Procedure

Subjects were seated in an anechoic room with eyes closed. They were informed that a male voice would be presented to one ear and a female voice to the other ear. All subjects performed

18 runs. The first two runs were passive control runs (Control Condition), in which the subjects only listened to the stimuli at rest, with the sidedness of presentation of either the male or the female voice being changed. The other 16 runs were 'count' runs (Task Condition). The subjects were required to count silently the number of times a particular syllable was presented in an ear ('target') for each run. Figure 1 illustrates one 'count' run. In this run, the syllable /ba/ by the male voice presented to the left ear was the target stimulus. Therefore, /ba/ is designated as the 'target syllable' in the figure, with the left ear designated as the 'attended channel'. The task condition consisted of the following 16 runs: eight target stimuli (4 target syllbles X 2 voices) X the two sides for the attended channel. The ordering of the 16 runs was randomized for all subjects, with the number of the target stimuli for each run being set between 18-26. After the conclusion of each run, the subjects were asked to give the number of the target stimuli detected.

The time of day for recording was always late morning. Each run lasted approximately 3 minutes, with a one-minute break between each run. All 18 runs lasted a total of about one hour.

III-3. EEG recording

After the experiment, the EEGs without artifacts were passed through a bandpass filter set at 1.5-25 Hz (-6dB/oct) and then digitized at a sampling frequency of 250 Hz/CH. Then, 16 EEG responses to each of the 8 stimuli were selected from each region (Cz, T3, T4) for each of the 18 runs.

For the control condition, the EEG responses to the 8 stimuli from each region were averaged separately for both sides of the stimulus presentation (left or right ear). The triggering point was the stimulus onset time, and the averaging period began 20 ms before the stimulus onset and lasted 620 ms thereafter. Thus, each ERP in the control condition consisted of 128 responses (8 stimuli X 16 responses).

For the task condition, the EEG responses derived from each region during the 16 runs for each subject were compiled and divided into four categories according to the sidedness of the stimulus presentation. The four categories were the following: 1) target syllables in the attended ear (N= 8 X 16= 128); 2) non-target syllables in the attended ear (N= 3 X 8 X 16= 384); 3) target syllables in the non-attended ear (N= 128); and 4) non-target syllables in the non-attended ear (N= 384). The EEG responses were averaged for each side of the stimulus presentation and for each category, separately, using a mini-computer (DEC, LSI-11/2). Thus, 8 ERPs (2 sides of stimulus presentation X 4 categories) were obtained from each region for each subject, and each ERP contained an equal number of responses to each of the 8 stimuli.

Each of the ERP components was defined as follows: N100 was

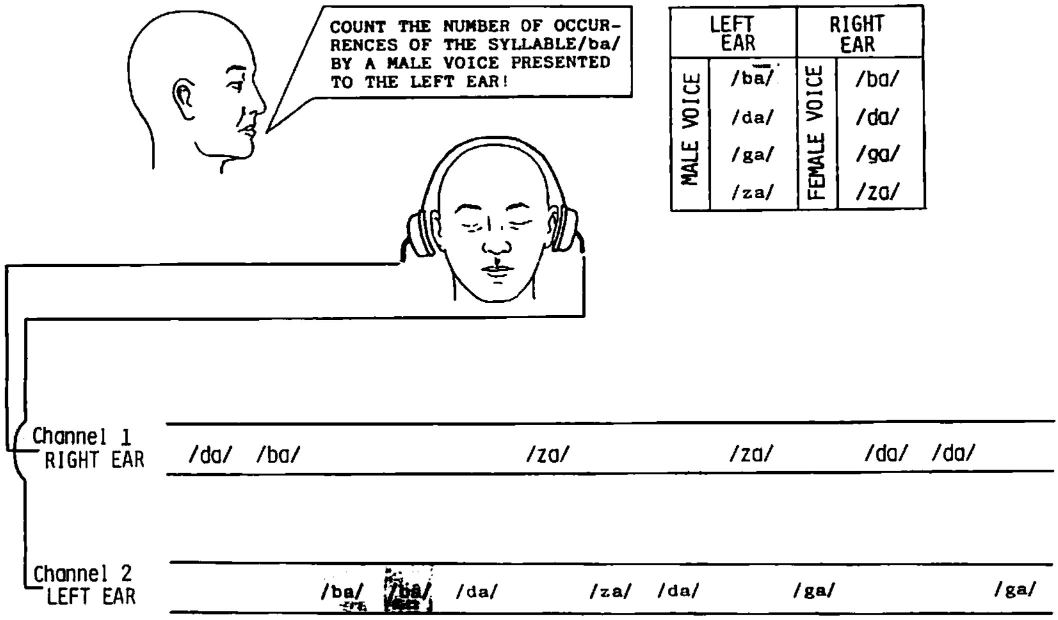


Figure 1. Illustration of syllable discrimination tasks -- an exsample of the 'count' runs. In this run, the syllable /ba/ by a male voice presented to the left ear was designated as the target stimulus.

Table 1. Mean amplitudes (µV) and latencies (msec) of the N100 and P200 components, as well as mean LPCs (µV), derived from the Cz, T3 and T4 regions for the control conditions. "LEFT EAR" and "RIGHT EAR" indicate conditions where the stimuli were presented to the left ear and the right ear, respectively. Values in parenthesis indicate standard deviations.

		N100		P200		LPC
		Amplitude	Latency	Amplitude	Latency	
Cz	LEFT EAR	4.08 (1.56)	93.8 (11.3)	3.87 (2.38)	191.2 (15.1)	−0.56(0.55)
	RIGHT EAR	3.15 (1.66)	95.6 (11.7)	4.13 (1.81)	190.0 (14.0)	−0.35(0.54)
T3	LEFT EAR	1.85 (0.98)	90.2 (15.7)	1.82 (1.54)	185.8 (23.6)	0.07(0.43)
	RIGHT EAR	1.92 (0.97)	95.8 (26.8)	1.23 (1.22)	188.2 (31.2)	0.01(0.48)
T4	LEFT EAR	2.56 (0.99)	109.2 (20.4)	1.96 (1.64)	199.6 (29.1)	0.03(0.56)
	RIGHT EAR	1.41 (0.88)	104.2 (15.7)	2.13 (1.17)	196.6 (22.9)	0.34(0.46)

the most negative peak in the 56-156 ms period after the stimulus onset; P200 was the most positive peak in the 40- 120 ms period after the N100 peak; the late positive component was the positive deflection in the 50-330 ms period after the P200 peak. Each amplitude of the ERP components was measured with respect to a zero level, which was defined as the mean amplitude during a 20 ms period pre- and post-stimulus.

III-4. Statistical analysis

The data obtained were analyzed utilizing the ANOVA program of the Statistical Package for the Social Sciences (SPSS). The ERPs derived from each region were analyzed employing the amplitudes and latencies of the N100 and P200 components, as well as the averaged amplitudes of the late positive components (abbr. LPC), as dependent variables. The covariant was age, and the independent variables (factors) were as follows.

1) In the control condition: SEX (male/female); EAR (the sidedness of the stimulus presentation, left/right).

2) In the task condition: SEX; EAR; CHANNEL (attend/non-attend); SYLLABLE (target/non-target).

For the purpose of comparison in terms of hemispheric functioning, the data of the ERPs derived from the T3 and T4 regions were combined and analyzed, adding the factor REGION (T3/T4) to the factors mentioned under both conditions.

Therefore, a Cz-ANOVA, T3-ANOVA, T4-ANOVA, and T3,T4-ANOVA were carried out for both conditions.

III-5. Estimation of performance levels

Performance levels for each subject in performing the tasks were estimated on the basis of Error Indexes (EIs). The EI for each run was calculated according to the following formula.

$$EI = \frac{|\text{number of target} - \text{subject's answer}|}{\text{number of target}} \quad X\ 100$$

IV. Results

The mean values (and standard deviations) of each component of the ERPs derived from each region are shown in Tables 1 and 2. Table 1 shows the means in the control condition for each ear (the sidedness of the stimulus presentation). Table 2 shows the means in the task condition for each channel (attend/non-attend) and syllable (target/non-target).

IV-1. Sex differences in ERPs

Table 2. Mean amplitudes (μV) and latencies (msec) of the N100 and P200 components, as well as mean LPCs (μV), derived from the Cz, T3 and T4 regions for the task conditions.

	CHANNEL	SYLLABLE	EAR	N100		P200		LPC
				Amplitude	Latency	Amplitude	Latency	
Cz	Attend	× Target	× Left	4.10 (2.26)	96.2 (10.7)	3.37 (1.98)	177.8 (15.6)	0.51 (0.94)
	Attend	× Target	× Righ	3.92 (2.19)	97.0 (7.8)	3.22 (1.58)	180.8 (17.6)	0.29 (1.01)
	Attend	× Non-target	× Left	4.09 (1.65)	97.6 (10.9)	2.67 (1.15)	180.8 (10.0)	−0.21 (0.86)
	Attend	× Non-target	× Right	4.20 (1.44)	98.8 (11.8)	2.95 (1.31)	181.6 (14.4)	−0.10 (0.72)
	Non-attend	× Target	× Left	3.48 (1.39)	97.6 (10.2)	4.43 (2.11)	186.0 (9.4)	−0.69 (0.91)
	Non-attend	× Target	× Right	3.87 (1.63)	96.2 (13.5)	3.77 (1.61)	186.0 (14.2)	−0.77 (0.78)
	Non-attend	× Non-target	× Left	3.40 (1.18)	96.4 (11.8)	4.39 (1.39)	183.8 (8.8)	−0.59 (0.46)
	Non-attend	× Non-target	× Right	3.36 (1.42)	98.4 (10.1)	4.10 (1.56)	183.8 (12.8)	−0.55 (0.60)
T3	Attend	× Target	× Left	1.73 (1.21)	100.2 (24.1)	1.12 (1.63)	179.0 (30.9)	0.59 (0.53)
	Attend	× Target	× Right	2.19 (1.21)	107.0 (23.9)	1.09 (1.30)	192.0 (24.0)	1.11 (0.92)
	Attend	× Non-target	× Left	1.64 (0.73)	93.6 (19.4)	0.82 (0.97)	170.9 (25.5)	0.02 (0.63)
	Attend	× Non-target	× Right	2.08 (0.81)	106.6 (18.7)	1.10 (1.11)	197.2 (26.7)	0.51 (0.55)
	Non-attend	× Target	× Left	1.71 (0.89)	89.0 (14.3)	1.80 (1.14)	177.0 (18.3)	−0.26 (0.45)
	Non-attend	× Target	× Right	2.00 (1.25)	96.0 (20.2)	1.58 (1.32)	190.6 (23.6)	0.12 (0.61)
	Non-attend	× Non-target	× Left	1.61 (0.92)	94.0 (16.9)	1.77 (0.94)	178.8 (18.1)	−0.19 (0.30)
	Non-attend	× Non-target	× Right	1.69 (0.86)	97.2 (19.8)	1.67 (0.99)	192.4 (28.5)	0.17 (0.44)
T4	Attend	× Target	× Left	2.39 (1.24)	109.6 (18.7)	1.82 (1.22)	198.4 (30.6)	0.65 (0.57)
	Attend	× Target	× Right	2.03 (1.24)	108.8 (17.1)	1.43 (0.96)	193.4 (24.0)	0.23 (0.61)
	Attend	× Non-target	× Left	2.31 (1.04)	113.6 (17.3)	1.64 (1.14)	198.2 (33.1)	0.40 (0.48)
	Attend	× Non-target	× Right	1.90 (0.80)	108.6 (17.3)	1.32 (1.06)	188.8 (25.7)	0.15 (0.46)
	Non-attend	× Target	× Left	1.87 (1.21)	112.6 (17.0)	2.54 (1.37)	200.6 (18.8)	0.32 (0.43)
	Non-attend	× Target	× Right	1.73 (0.94)	103.0 (20.2)	1.95 (1.33)	187.8 (24.6)	−0.10 (0.41)
	Non-attend	× Non-target	× Left	1.85 (0.83)	109.2 (15.7)	2.51 (1.27)	192.4 (27.4)	0.24 (0.33)
	Non-attend	× Non-target	× Right	1.47 (0.75)	100.8 (18.8)	1.98 (1.17)	187.2 (19.0)	−0.12 (0.26)

Table 3. The effects of the factors EAR and REGION, as well as the interaction of REGION X EAR, in the ANOVA results for the amplitudes and latencies of the N100 and P200 components, as well as LPCs, in the task conditions. Values indicate F-values.

	N100AMP	N100LAT	P200AMP	P200LAT	LPC
Cz: EAR	0.0	0.1	0.6	0.2	0.0
T3: EAR	4.3*	5.9*	0.0	17.7**	18.1**
T4: EAR	4.4*	4.3*	7.0**	4.0*	23.9**
T3・T4: REGION	1.0	24.3**	16.9**	9.4**	0.9
T3・T4: REGION×EAR	8.7**	10.3**	2.8(*)	19.3**	40.7**

(*); $p<0.1$ *; $p<0.05$ **; $p<0.01$

Table 4. The effects of the factors CHANNEL and SYLLABLE,as well as the interaction of CHANNEL X SYLLABLE, in the ANOVA results for the amplitudes and latencies of the N100 and P200 components, as well as LPCs, in the task conditions. Values indicate F-values.

		N100		P200		LPC
		AMP	LAT	AMP	LAT	
Cz	CHANNEL	4.6*	0.0	19.2**	4.7*	37.6**
	SYLLABLE	0.1	0.3	0.4	0.0	2.3
	CHANNEL×SYLLABLE	0.7	0.0	1.5	0.9	7.9**
T3	CHANNEL	1.0	6.4*	12.8**	0.0	47.9**
	SYLLABLE	1.0	0.0	0.0	0.0	5.5*
	CHANNEL×SYLLABLE	0.1	1.1	0.2	0.1	9.0**
T4	CHANNEL	7.6**	1.7	16.3**	0.4	13.7**
	SYLLABLE	0.6	0.2	0.1	0.7	2.1
	CHANNEL×SYLLABLE	0.0	0.6	0.1	0.0	0.6

*; $p<0.05$ **; $p<0.01$

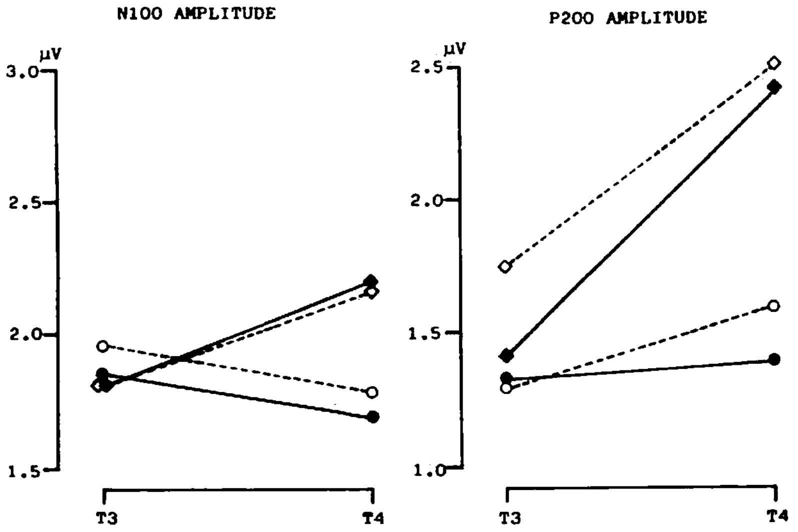


Figure 2. Mean amplitudes of the N100 component (left side) and P200 component (right side) at the T3 and T4 regions. Control conditions: Males◇---◇; Females○----○. Task conditions: Males ◆——◆; Females●——●.

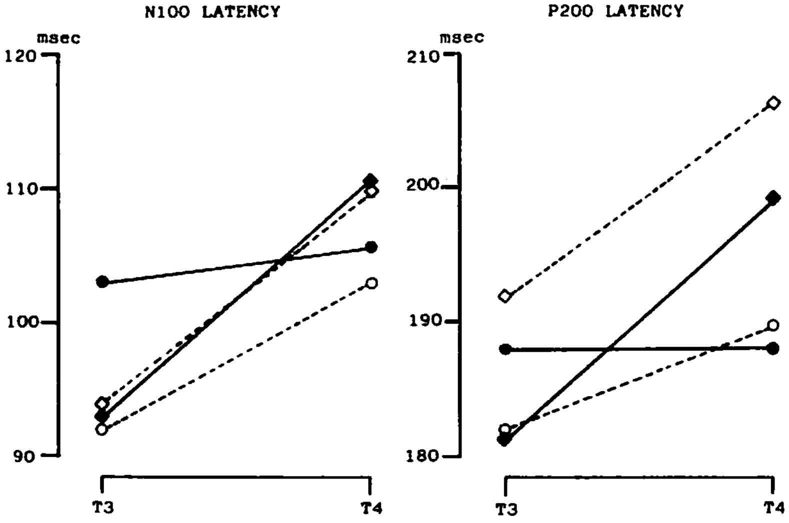


Figure 3. Mean latencies of the N100 component (left side) and P200 component (right side) at the T3 and T4 regions. Control conditions: Males◇---◇; Females○---○. Task conditions: Males ◆——◆; Females●——●.

The main effect of the factor SEX was significant on the amplitude of the P200 component derived from the T4 region (T4-P200) and the latency of T4-P200 in the control condition [$F(1,35)= 5.20$, $p< 0.05$; $F(1,35)= 5.94$, $p< 0.05$, respectively]. In the task condition, the main effect of SEX was significant on the latency of T3-N100 [$F(1,143)= 7.41$, $p< 0.01$]; the amplitude of T4-N100 [$F(1,143)= 4.55$, $p< 0.01$]; the amplitude of T4-P200 [$F(1,143)= 37.54$, $p< 0.01$]; and the latency of the T4-P200 [$F(1,143)= 5.15$, $p< 0.01$].

Differences in the lateral asymmetries of both hemispheres between both sexes were examined employing the interaction of SEX X REGION in the T3,T4-ANOVA as indexes. In the control condition, the interaction of SEX X REGION was not significant for any of the components. In the task condition, this interaction was significant for the N100 amplitude [$F(1,287)= 5.55$, $p< 0.05$]; the N100 latency [$F(1,287)= 12.57$, $p< 0.01$]; the P200 amplitude [$F(1,287)= 13.23$, $p< 0.01$]; and the P200 latency [$F(1,287)= 9.56$, $p< 0.05$]. Figs. 2 and 3 show these sex differences in the task condition. As shown in these figures, the differences between T3 and T4 were smallar in the females than in the males in terms of the amplitudes and latencies of the N100 and P200 components.

None of the interactions between SEX and the other factors, nor any of the 3-way interactions between SEX X REGION and the other factors, was significant.

IV-2. Ear differences in ERPs

In the control condition, the main effect of EAR, that is, the sidedness of the stimulus presentation, was significant only for the amplitude of T4-N100 [$F(1,35)= 15.37$, $p< 0.01$].

In the task condition, the main effect of EAR was not significant for the Cz-ANOVA. However, this effect was significant for all components in the T3-ANOVA and the T4-ANOVA, except for the amplitude of T3-P200 (see Table 3).

The interaction of EAR X REGION in the T3,T4-ANOVA was significant only for the N100 amplitude in the control condition. At the same time, in the task condition, this interaction was significant for all components, with the exception of the P200 amplitude, which showed only a tenden-cy toward such an interaction (see Table 3).

Fig. 4 shows the interactive effect of EAR X REGION on the N100 and P200 amplitudes. As shown in this figure, the amplitudes of T3-N100 and T4-N100 in the task condition were larger when stimuli were presented to the ear contralateral to the EEG-deriving side than when the stimuli were presented to the ipsilateral ear. The amplitude of T4-P200 in the task condition was larger when stimuli were presented to the contralateral ear (left ear) than to the ipsilateral ear (right ear). However, the amplitude of T3-P200 remained equal irrespective of the sidedness of

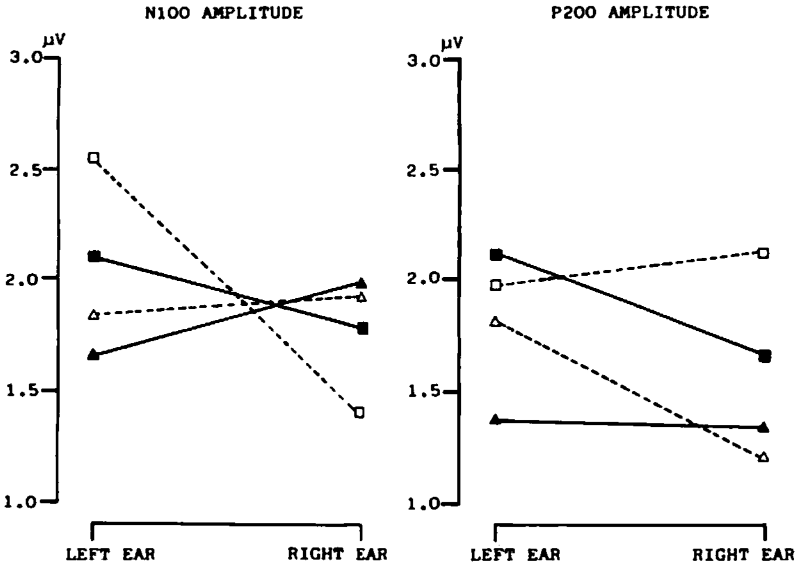


Figure 4. Mean amplitudes of the N100 component (left side) and P200 component (right side) at the T3 and T4 regions. "LEFT EAR" and "RIGHT EAR" indicate conditions where the stimuli were presented to the left ear and the right ear, respectively. Control conditions: T3△---△; T4□---□. Task conditions T3▲——▲; T4■——■.

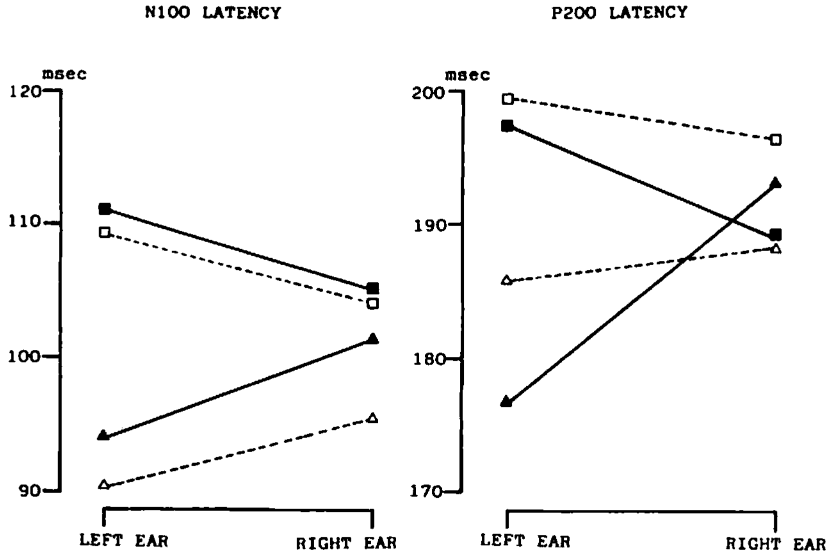


Figure 5. Mean latencies of the N100 component (left side) and P200 component (right side) at the T3 and T4 regions. Control conditions T3△---△; T4□---□. Task conditions: T3▲——▲; T4■——■.

the stimulus presentation. The amplitude of T3-P200 in the task condition was reduced for stimuli presented to the ipsilateral ear and enhanced for stimuli presented to the contralateral ear, in comparison to the control condition.

Fig. 5 shows the interactive effect of EAR X REGION on the N100 and P200 latencies. As shown in this figure, in the task conditions, the latencies of T3-N100, T4-N100, T3-P200, and T4-P200 were longer when the stimuli were presented to the ipsilateral ear than when presented to the contralateral ear. None of the 3-way interactions between EAR X REGION and the other remaining factors was significant.

IV-3. Asymmetry of ERPs

The effect of REGION was not significant on the amplitude of the N100 component or that of the LPC in either condition. However, REGION was significant on the N100 latency in the control condition [$F(1,71)= 9.37$, $p<0.01$] and in the task condition [$F(1,287)= 24.31$, $p<0.01$]. The effect of REGION on the P200 amplitude tended to be significant in the control condition [$F(1,71)= 2.80$, $p<0.1$] and was significant in the task condition [$F(1,287)= 16.92$, $p<0.01$]. For the P200 latency, this effect was significant in the task condition [$F(1,287)= 9.40$, $p<0.01$], and tended to be significant in the control condition [$F(1,71)=3.51$, $p<0.1$].

Thus, as shown in Figs. 4 and 5, the amplitude of T4-P200 was larger than that of T3-P200, and the latencies of T3-N100 and T3-P200 were shorter than those of T4-N100 and T4-P200, respectively. REGION and the remaining factors had no significant interactive effect on the amplitudes and latencies of the N100 and P200 components, with the exceptions of REGION X SEX and REGION X EAR, as mentioned above.

The effect of REGION on LPC was not significant. However, the interactive effect of REGION X EAR and REGION X CHANNEL on LPC was significant.

IV-4. Selective attention and ERPs

IV-4-1. Selective attention and amplitudes of the N100 and P200 components

The main effect of CHANNEL was significant on the amplitudes of Cz-N100 and T4-N100, but not on the amplitude of T3-N100 (see Table 4). This effect of CHANNEL indicates that the amplitudes of Cz-N100 and T4-N100 were larger when stimuli were presented to the attended channel as compared to the non-attended channel (Fig. 6).

The effect of CHANNEL was significant for the amplitudes of

Cz-P200 , T3-P200 and T4-P200. Contrary to the N100 amplitudes, the P200 amplitudes elicited by the stimuli presented to the non-attended channel were larger than those of the stimuli presented to the attended channel (Fig. 6).

In the task condition, in contrast to the control condition, the N100 amplitudes were enhanced, and the P200 am-plitudes were reduced, when the stimuli were presented to the attended channel.

IV-4-2. Selective attention and latencies of N100 and P200 components

The effect of CHANNEL was significant only for the latencies of T3-N100 and Cz-P200. The latency of T3-N100 was longer, and the latency of Cz-P200 was shorter, when the stimuli were presented to the attended channel than when presented to the non-attended channel (Fig. 7). The effect of SYLLABLE and the interaction of CHANNEL X SYLLABLE were not significant for the N100 and P200 components.

IV-4-3. Selective attention and LPC

The effect of CHANNEL and the interactive effect of CHANNEL X SYLLABLE on Cz-LPC were significant. Furthermore, the effect of SYLLABLE on Cz-LPC was significant when the stimuli were presented to the attended channel. However, the effect of SYLLABLE on Cz-LPC was not significant when the stimuli were presented to the non-attended channel. Thus, the Cz-LPC elicited by the target syllable in the attended channel (i.e., target stimuli) was the largest (Fig. 8).

As for T3-LPC, the effects of CHANNEL and SYLLABLE, as well as the interaction of CHANNEL X SYLLABLE, were significant. Thus, the T3-LPC elicited by the target syllable in the attended channel was the largest. However, only the effect of CHANNEL was significant for T4-LPC. Thus, T4-LPC was not significantly enhanced by the target syllable in the attended channel (Fig. 8).

VI-4-4. Asymmetry of LPC

In the T3,T4-ANOVA, the effect of REGION was not significant, but the interactions of REGION X EAR and REGION X CHANNEL were significant [$F(1,287)= 40.70$, $p<0.01$; $F(1,287)= 9.6$, $p<0.01$, respectively], and the interaction of REGION X CHANNEL X SYLLABLE tended toward significace [$F(1,287)= 3.4$, $p<0.1$]. Furthermore, the interaction of REGION X SYLLABLE tended toward significace [$F(1,151)= 2.94$, $p<0.1$] when the stimuli were presented to the attended channel, with this interaction not being significant when the stimuli were presented to the non-attended channel. Therefore, the asymmetry in LPC was largest when the target syllables were presented to the attended channel (see Figs. 8 and 9).

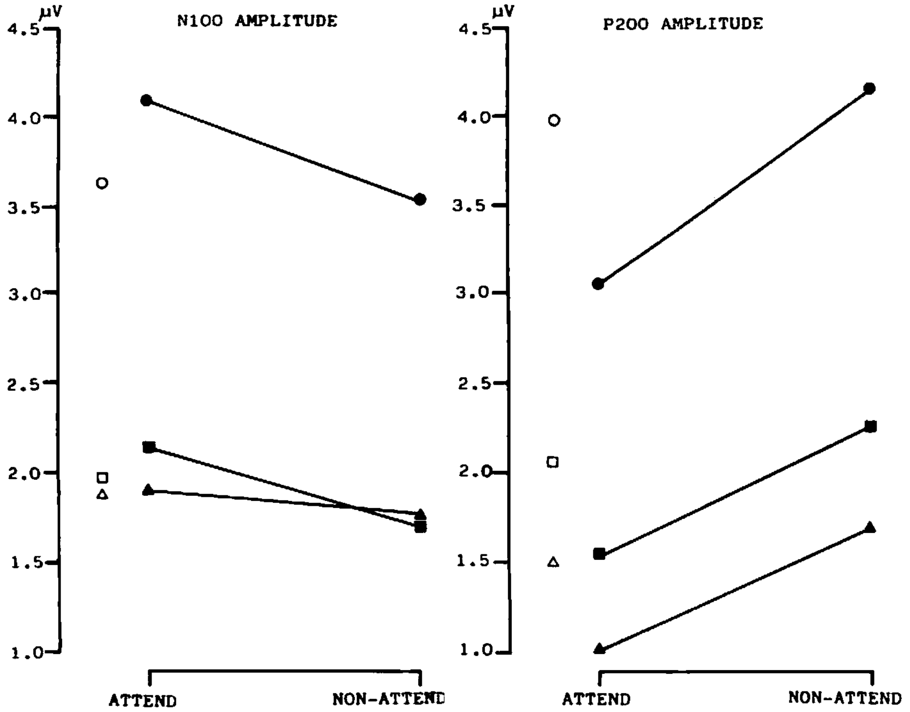


Figure 6. Mean amplitudes of the N100 component (left side) and P200 component (right side) at the Cz, T3 and T4 regions. "ATTEND" and "NON-ATTEND" indicate conditions when the stimuli were presented to the attended ear and the non-attended ear, respectively. Control conditions: Cz ○ ; T3 △ ; T4 □ . Task conditions: Cz ●——●; T3 ▲——▲ ; T4 ■——■ .

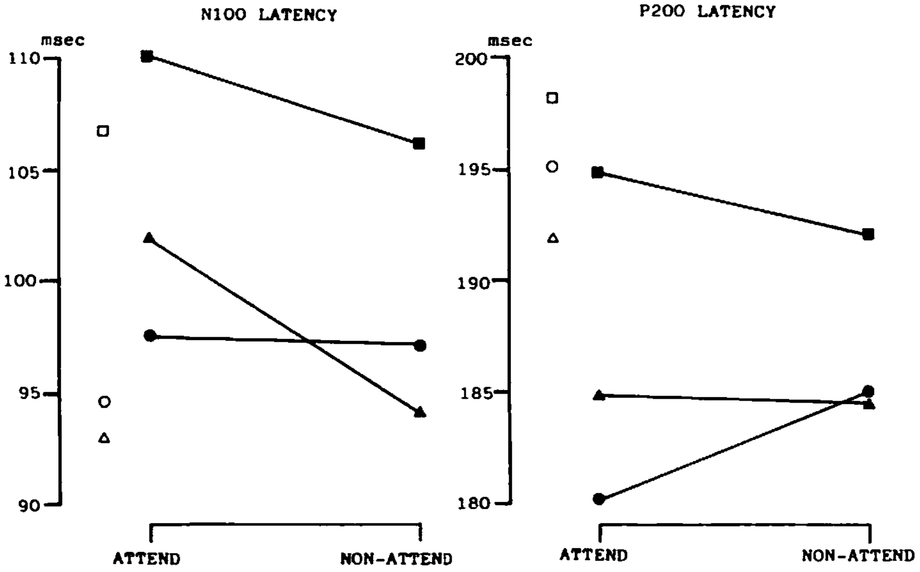
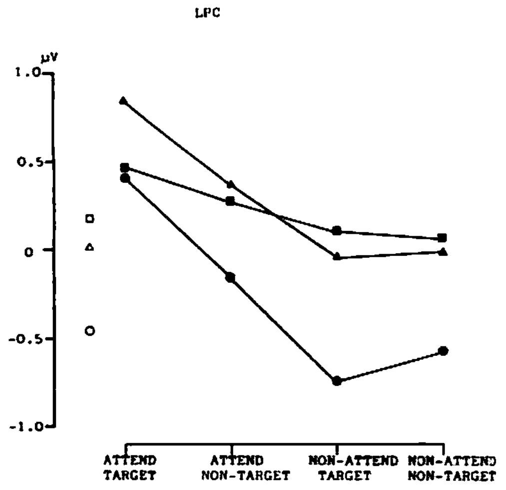


Figure 7. Mean latencies of the N100 component (left side) and P200 component (right side) at the Cz, T3 and T4 regions. Control condition: Cz ○ ; T3 △ ; T4 □ . Task conditions: Cz ●——●; T3 ▲——▲; T4 ■——■ .



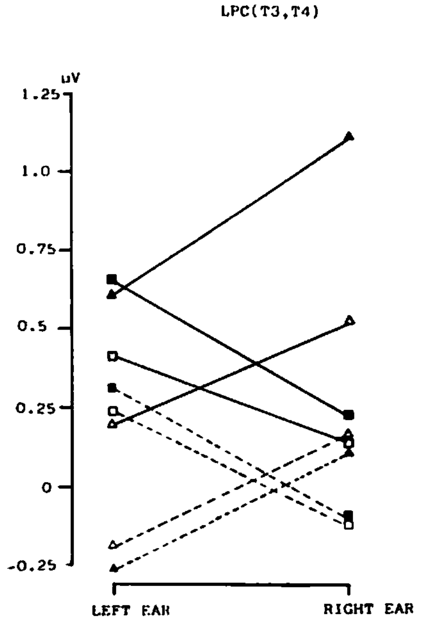


Figure 8. Mean LPCs at the Cz, T3 and T4 regions. "ATTEND TARGET": target stimuli in the attended ear. "ATTEND NON-TARGET": non-target stimuli in the attended ear. "NON-ATTEND TARGET": the same syllables as the target stimuli in the non-attended ear."NON-ATTENDED NON-TARGET": syllables different from the target stimuli in the non-attended ear. Control conditions: Cz ○ ; T3 △ ; T4 □ . Task conditions: Cz ●——● ; T3 ▲——▲ ; T4 ■——■ .

Figure 9. Mean LPCs at the T3 and T4 regions. "LEFT EAR" and "RIGHT EAR" indicate conditions where the stimuli were presented to the left ear and the right ear, respectively. T3 △ , ▲ ; T4 □ , ■ . Attend target ▲——▲ ■——■; Attend non-target △——△ □——□; Non-attend target ▲- - -▲ ■- - -■; Non-attend non-target △- - -△ □- - -□.

Table 5. Correlations between error indexes (EIs) and LPCs. "LEFT EAR" and "RIGHT EAR" indicate conditions when the target stimuli were presented to the left ear and the right ear, respectively. Values indicate Pearson's correlation coefficients.

	LEFT EAR	RIGHT EAR
Cz-LPC	-0.42 ($p<0.05$)	-0.32 ($p<0.10$)
T3-LPC	-0.10 (n.s.)	-0.60 ($p<0.01$)
T4-LPC	-0.45 ($p<0.05$)	-0.28 (n.s.)

The interaction of REGION X EAR was always significant on LPCs elicited under all four categories of stimuli presentation (see Fig. 9). In addition, although not statistically significant, the ear differences for T3-LPC and T4-LPC were largest when the target syllables were presented to the attended channel, as shown in Fig. 9.

IV-5. Performance levels and ERPs

The mean value of EI (Error Index; see III-5.) across all subjects for all target stimuli was 5.3%. The mean value of EI for the target stimuli presented to the left ear was 4.0%, and 6.6% for the right ear. The difference in EI between the target stimuli presented to both ears was not significant [t(1,38)= -0.93, n.s.].

When Pearson's correlations between EIs and each component of the ERPs elicited by the target stimuli were calculated, significant correlations were obtained only between EIs and LPCs. Table 5 shows the correlation between EIs and LPCs for each side of the stimulus presentation. The EIs for the target stimuli presented to the left ear correlated inversely with the Cz-LPCs and T4-LPCs elicited by the target stimuli presented to the left ear. The EIs for the target stimuli presented to the right ear correlated inversely with the T3-LPCs and Cz-LPCs elicited by the target stimuli presented to the right ear.

V. Discussion

V-1. Sex differences in ERP asymmetry

No sex differences were found in any of the ERP components derived from the Cz region in the control condition or in the task condition. However, differences were found in some of the ERP components derived from the T3 and T4 regions under both conditions. The most remarkable finding was that the interaction between SEX and REGION was significant for the amplitudes as well as latencies of the N100 and P200 components in the task condition. This result indicates that males display a greater degree of asymmetry for the N100 and P200 components in both hemispheres compared to females.

A number of investigators have reported sex differences in hemispheric specialization. McGlone[5-6] studied 85 dextrals with unilateral brain injuries and found that only men showed the expected pattern of verbal and performance I.Q. deficits, depending on the laterality of the lesions. McGlone also reported that, in female the verbal and performance I.Q. scores were not significantly different whether the lesion was on the right or left side. A stronger right-ear superiority in verbal dichotic listening tests was found for males by Lake and Bryden[7]. Levy and

Reid[8] have reported that whether the tests are verbal or visuospatial, females display a relatively smaller sensory field asymmetry than males in tachistoscopic presentation of tests. Other investigators have also reported that cerebral lateralization is of lesser degree in females than in males[9-10].

In the field of neurophysiological research, Flor-Henry[11] has studied the power spectra EEG characteristics of normal dextral males and females. He found that during verbal activation, males showed a significant increase in right temporal power (13-20 Hz) compared to a resting situation. Females, in this situation, on the other hand, showed a significant decrease in parietal power bilaterally.

Our study is consistent with previous studies mentioned above in the finding that male subjects display a greater degree of hemispheric asymmetry than female subjects.

Furthermore, since sex differences in hemispheric asymmetry were not clearly observed under the control condition, but rather became obvious under the task condition, it can be suggested that the process of the active perception of stimuli makes for such observable sex differences.

V-2. Effect of contralateral stimulation on auditory neuronal pathways

The interactive effect of EAR (sidedness of stimulus presentation) and REGION (EEG-deriving side) was significant for all components under the task condition. Specifically, stimuli presented to the ear contralateral to the EEG-source side elicited larger amplitudes and longer latencies for all components as compared to the stimuli presented to the ipsi-lateral ear.

Anatomically, it is well known that a partial cross exists in the auditory pathways to the cerebral auditory center. In a series of studies, Kimura[12-17] reported that normal subjects demonstrated right ear superiority for digits and left ear superiority for melodies during dichotic listening tests. Sparks and Geschwind[18] and Milner et al.[19] reported that after sectioning of the neocortical commissures patients could not report verbal input to the left ear if different verbal stimuli had been channeled simultaneously to the right ear. However, with monaural stimulation, such patients showed an equal accuracy of reports for both ears. Kimura claimed that when ipsilateral and contralateral inputs compete in the auditory system, the stronger contralateral input inhibits or occludes the ipsilateral signals. Recently, the right ear has been found to be superior for nonsense CV syllables in dichotic presentation[20].

In order to investigate such a competition between contralateral and ipsilateral auditory pathways in neurophysiological terms, ERPs have been recorded during dichotic presentation[21-22]. Haaland[21] presented different CVC monosyllables to subjects dichotically. Accuracy for right ear input was higher than that for left ear input. However, there was no difference in the ERP components derived from T3, T4, F7 and F8 between the two conditions, that is, the right-ear input alone being accurately identified and vice versa. Saitoh et al.22) recorded ERPs during dichotic detection tasks, in which subjects were required to attend to one channel, counting infrequent FM sounds in the attended channel. However, they could not find any difference in the N100 and P200 components between the T3 and T4 regions in the case of attending to the respective contralateral ear. A possible explanation for this, is that, although a stronger contralateral input is expected to inhibit or occlude ipsilateral signals, it is difficult to discriminate between two different electrophysiological responses to two different stimuli presented simultaneously.

To resolve such difficulty in utilizing ERPs for investigating the competition between the contralateral and ipsilateral auditory pathways during dichotic presentations, several investigators have attempted to examine auditory pathway effects under monaural presentations. Wolpaw and Penry23-24) reported that under the monaural presentation of nonverbal stimuli the N1-P2 amplitude derived from the mid-temporal region contralateral to the sidedness of the stimulus presentation was larger than derived from the ipsilateral region. On the other hand, Neville25) has reported that, under the monaural presentation of verbal as well as nonverbal stimuli, he could not find an interaction between ear and hemisphere. There has been some disagreement in previous studies concerning the auditory pathway effect under monaural presentations. There is one methodological problem in these studies; that is, only one ear is stimulated in one session. In this case, competition between contralateral and ipsilateral auditory pathways does not occur. To avoid this problem, several investigators have recorded ERPs under conditions in which stimuli are presented randomly to both ears in one session. Tanguay et al.26) have reported that verbal stimuli presented to the contralateral ear elicited a larger N1-P2 amplitude than stimuli presented to the ipsilateral ear, in both central and Wernicke areas. On the other hand, Haaland21) has reported that neither the amplitude of the N100 nor the P200 component was affected by the sidedness of stimulus presentation in the anterior- or mid-temporal region. Furthermore, Taub et al.27) have found that only left ear stimulation by music chords elicited a larger N1-P2 amplitude in the right Wernicke area as compared to the left. The interstimulus intervals in these three studies were relatively long, that is, 3 sec in the study of Tanguay et al., 4 sec in the study of Taub et al., and 8 sec in Haaland's study. Moreover, the subjects of Tanguay et al. and Taub et al. were studied under no psychological tasks. In the case of Haaland's study, the subjects were required to write the initial consonant heard after each presentation of CVC syllables, so the stimulus presentation was interrupted.

Considering these points, it seems necessary to set up a condition similar to that in dichotic listening tasks and that stimuli should be presented randomly to both ears with relatively short ISIs under a psychological task. In the syllable discrimination tasks employed by Hink et al.1), the stimuli were presented randomly to both ears with short ISIs (300-500 ms), and subjects were required to attend to one channel, counting a particular syllable in that channel. The procedure employed by Hink et al. can be regarded as similar to dichotic listening tasks. They found that N100 amplitudes were larger when stimuli were presented to the contralateral ear than the ipsilateral ear. However, they found no difference in the P300 amplitude regardless of the sidedness of the stimulus presentation. Their results seem to have been influenced by their recording locations, these being, not temporal, but near central regions (lateral to C3 and C4 by 10% of the inter-aural distance).

In this study, ERPs were recorded during syllable discrimination tasks similar to those employed by Hink et al., and the interactive effect of REGION (T3/T4) and EAR (the sidedness of the stimulus presentation) on the amplitudes and latencies of each ERP component was examined. As a result, an interaction between REGION and EAR was observed. Amplitudes were larger, and latencies were longer when the stimuli were presented to the contralateral ear as opposed to the ipsilateral ear. This result lends support in neurophysiological terms to the central competition hypothesis in dichotic listening tasks.

Furthermore, the interactive effect between REGION and EAR was found for latencies of each ERP component in this study, although previous authors 23-27) have not found such an interactive effect. Specifically, stimuli contralateral to EEG-deriving sides produced longer latencies as compared to ipsilateral stimuli. This prolongation of latencies was thought to be independent of a secondary prolongation due to a primary increase in the amplitudes of ERP components, since this prolongation of latencies was not in proportion to the increase of amplitudes, as seen in Figs 4 and 5. Hence, this result also lends support to the central competition hypothesis in dichotic listening tasks.

V-3. Selective attention and ERPs

Employing syllable discrimination tasks, Hink et al. reported that the amplitude of the N100 component derived from the Cz region was enhanced for all stimuli in the attended ear, while the amplitude of the P300 component was enhanced only for target stimuli in the same ear. They also concluded that channel selective attention ('stim-ulus set' as defined by Broadbent) corresponded to the N100 component, with target detection ('response set' as defined by Broadbent) corresponding to the P300 component. In comparing the results of this study with those of Hink et al., we can conclude that their results were replicated.

Although only a few reports have mentioned the effect of selective attention on the P200 component22,28), it was observed in this study that the amplitude of Cz-P200 was reduced for the stimuli in the attended channel.

We further compared the degree of increase in the N100 amplitude and the degree of decrease in the P200 component in the attended channel. The degree of increase in the N100 amplitude tended to be smaller than that of the decrease in the P200 amplitude [$F(1,143)=2.88$, $p<0.1$].

Hansen and Hillyard[29) have reported that when ERPs elicited by the stimuli in the non-attended channel were subtracted from those elicited by the stimuli in the attended channel, a prolonged negative component with a peak latency of approximately 200 ms was observed. They concluded that the enhancement of the N100 component by selective attention was due to the overlapping of this endogenous negative component with the exogenous N100 component. It may be speculated that this endogenous negative component produced the increase of the N100 amplitude as well as the decrease of the P200 amplitude for the attended channel in our study. In addition, the result that the degree of increase in the N100 amplitude was smaller than that of the decrease in the P200 amplitude suggests that the endogenous negative component displayed a larger amplitude at a latency of nearly 200ms compared to that of 100 ms. This suggestion seems to be in accordance with Hansen and Hillyard's conclusion in that the negative component reached its peak in approximately 200 ms.

Moreover, the result of Hink et al. that target stimuli in the attended channel produced the largest Cz-LPC among all their stimuli was also replicated in this study. The Cz-LPC correlated inversely with the performance levels for the target detection (EI). Donchin[30) has proposed that the P300 component reflects the stimulus evaluation process. Based on the result that Cz-LPC was enhanced for the target stimuli and the result that the Cz-LPC elicited by the target stimuli correlated with the performance levels, it can be concluded that the LPC reflects the stimulus evaluation process as reported by Donchin.

In summary, it can be said that the amplitudes of the N100 and P200 components reflect channel selective attention ('stimulus set' as defined by Broadbent), with the LPC reflecting the process of stimulus evaluation and response selection ('response set' as defined by Broadbent). This is in agreement with the position of Hillyard et al.[2,31-33), as well as that of Donchin et al.[30,34-35).

V-4. Selective attention and the lateralized function of the cerebral hemispheres

Concerning ERPs derived from the C3' and C4' regions, Hink et al. made inference only regarding ear differences but not regarding an effect for selective attention. There are few previous reports discussing ERPs derived from both hemispheres in relation to selective attention. In our study, the amplitudes of T4-N100, T3-P200 and T4-P200 displayed an effect for channel selection in a way similar to those observed for the ERPs of the Cz. The amplitude of T3-N100 failed to show an effect of channel selection. It can be suggested that the N100 and P200 components reflect channel selective attention in the T4 region, as well as the Cz region, and in part in the T3 region. The T3-LPC and T4-LPC elicited by the target stimuli presented to the respective contralateral ear correlated with the performance levels for detecting these target stimuli. Therefore, T3-LPC and T4-LPC reflect stimulus evaluation and response selection in a way similar to those observed for Cz-LPC.

Target stimuli produced significantly larger values of T3-LPC as compared to those of T4-LPC. In comparing the LPCs elicited by all the stimuli within one region, a significant enhancement of LPC for target stimuli was observed just in the T3 region. Based on these results, it may be speculated that the left hemispheric dominance for verbal tasks, such as those employed in this study, is reflected in an asymmetry of LPCs. This finding lends support to the notion of Berlin20) that the right ear is superior for CV syllables in dichotic listening tasks.

The finding that the left hemispheric dominance for verbal tasks was reflected in LPCs, but not in N100 nor P200, may suggest that this hemispheric dominance is more marked in the process of stimulus evaluation - that is, the response set - as compared to the stimulus set as defined by Broadbent. Certain previous authors have reported an ERP asymmetry during the semantic processing of language36). Megela and Teylar37) designed an experiment to test semantic influences on ERPs using synonyms and homonyms, and reported that P300 was larger in T3 than in T4. Thatcher38) reported that P400 derived from the T5 region was larger than that from T6 for visual ERPs during semantic matching tasks. Goto et al.39) reported that P400 at T5 was larger than that at T6 for auditory ERPs during semantic matching tasks similar to those employed by Thatcher. Our results are in agreement with these results in that the left hemisphere produced larger late positive components of ERPs during verbal tasks as compared to the right hemisphere.

Moreover, the result that performance levels for detecting target stimuli in the attended ear correlated only with LPCs of the contralateral hemisphere lends support to our previous notion 22,40) that the hemisphere contralateral to the attended ear is selectively activated during dichotic detection tasks.

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