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Differential effects of alcohol on the cortical processing of foreign and native language

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Abstract

The effect of alcohol (ethanol) on cortical processing of Finnish vs. English words in Finnish-speaking subjects was studied by recording auditory event-related potentials in 10 subjects who had started studying English at the age of 9–10 years. At the beginning of the block of 100 words, the subject heard an introductory sentence. Half of the words completed the sentence well and the other half did not. The subject pressed a reaction key immediately after hearing a proper word. After the control condition, the subject ingested alcohol (1 ml/kg). Alcohol attenuated the amplitude of N100 to both Finnish and English words, this attenuation being significantly stronger for English than for Finnish words. The early differential effect of alcohol suggests that language-specific information is extracted in the cortex already approximately 100 ms from the word onset. The results are in line with animal experiments demonstrating that alcohol selectively affects the activity of single units involved in newer forms of behavior. © 1998 Elsevier Science B.V.

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1. Introduction

Acute effects of alcohol on human brain functions are reflected in event-related potentials (ERPs) but the available literature contains many contradictions. Alcohol has been shown to decrease hemispheric asymmetry affecting the right hemisphere to a larger extent than the left hemisphere (Porjesz and Begleiter, 1979). However, using auditory stimuli, Campbell and Lowick (1987) found no such effects. Further, alcohol has

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been shown to affect (Daruna et al., 1987) or not to affect (Rohrbaugh et al., 1987) the amplitude of the auditory N100 deflection, peaking approximately 100 ms after the onset of an auditory stimulus. In the same vein, there is evidence that alcohol decreases the amplitude of the later evoked potential deflections (Campbell and Lowick, 1987; Lukas et al., 1990), whereas some research groups (Sommer et al., 1993; Daruna et al., 1987) have shown that the amplitudes actually increase. In addition, alcohol has been suggested to have an influence on the ERP in a difficult but not in an easy task (Rohrbaugh et al., 1987), in an easy but not in a difficult task (Campbell et al., 1984), or in both (Oscar-Berman, 1987). Also, there is evidence that the alcohol effect is larger for target than for non-target stimuli (Rohrbaugh et al., 1987), or vice versa (Campbell and Lowick, 1987). These various contradictions led Daruna et al. (1987) to conclude that alcohol effects on ERPs depend on the nature of the subject's task.

In explaining its effects on human ERPs, it is useful to consider alcohol influences on single neurons. However, such data mostly originate from experiments with immobilized and/or anaesthetized preparations; experiments with awake animals are rare (Klemm et al., 1976; Chapin and Woodward, 1989). Interestingly, alcohol may even affect close-by neurons in quite different ways, but it was not clear what was the underlying reason for this difference in sensitivity (Zornetzer et al., 1982, p. 107). However, on the basis of results obtained from behaving adult animals, Alexandrov et al. 1990, Alexandrov et al., 1991, 1993) have shown that the behavioral specialization of a neuron determines alcohol's action. Acute alcohol administration (1 g/kg) decreased the number of active neurons. This was due to selective depression of neurons involved in recent forms of behavior, formed at late stages of individual development. Not only in adults but also in early ontogenesis (4–7-day-old altricial nestlings of the pied flycatcher) alcohol primarily affected brain mechanisms subserving recently formed behavior (Alexandrov and Alexandrov, 1993)

On the basis of these single-unit data, it is proposed that one important factor determining the alcohol effect on human ERP is the 'age' of those functional neuronal systems which are involved in task performance. The goal of the present study was to compare the acute effect of alcohol on the ERPs related to the use of knowledge and experiences acquired at the early or later stages of individual development in an identical experimental task. Specifically, it was studied whether alcohol has a differential effect on the ERPs when a subject categorizes native vs. foreign words.

2. Methods

2.1. Subjects

Ten subjects (21–32 years, median 22 years, one female) participated in the experiment. All subjects reported having normal hearing. The subjects reported history of social drinking but not alcohol abuse. They also denied alcoholism in their families. All of them had started studying English at the age of 9–10 years and understood the language well. Due to its bad quality, the data of one subject was rejected from the final analysis.

2.2. Stimuli

The stimuli were presented in 12 blocks, half of them consisting of English words and the other half of Finnish words. There were approximately 100 words in each block. The words were originally spoken by a native Finnish female speaker, an English teacher by profession, with very good command of English language. The audiotaped words were digitized and presented binaurally through headphones to the subject by a computer. The mean number of letters in the English words was 7.6 and in the Finnish words 7.8. The duration of the acoustical stimuli was not measured. The constant interval between consecutive word onsets was 1.5 s. The intensity of the stimuli, embedded in continuous white noise, was approximately 80 dB SPL.

2.3. Procedure

Subjects were asked not to eat during the 4 h preceding the experiment which was carried out in an electrically shielded room where the subject was sitting in a reclining chair. The subject's alcohol level was measured with an alcometer (Driveguard A6301-33, Taiwan) before the experiment. In the control condition, the subject listened to three Finnish word sequences and three English word sequences. To avoid eye movements, he/she was fixating on a dot on the opposite wall of the recording chamber. Half of the subjects started with Finnish word sequences, half with English word sequences administered in an alternating order.

In the beginning of each word sequence, the subject heard an introductory sentence of type 'People eat—.' Half of the words completed the sentence in a semantically concordant way and the other half did not (bread vs. scientists, for example). The subject pressed a response key immediately after hearing a concordant word and refrained from pressing the key when the word was discordant or unknown to him/her. Before the start of the experiment, the subject practiced the task for some minutes. The practicing was stopped when the subject reported that he/she was acquainted with the task and could categorize and respond appropriately.

During the break, the subject was given ethanol (1 ml/kg) mixed with juice to a 20% solution. The time needed to finish the drink was approximately 20 min. Another 15 min were allowed to pass (to reach a plateau in the alcohol concentration curve) before the alcohol level was measured. The alcohol condition was identical to the control condition, but different word lists were used. Those lists were presented in the alcohol condition to half of the subjects and the remaining half was presented with the control condition. At the end of the experiment, the alcohol level was measured again. Presentation of the alcohol condition (always) after the control condition was not expected to cause such differential effects of alcohol which were in the focus of the present study.

2.4. Recording

The EEG was recorded from Fz, Cz, Pz, F3 and F4 electrodes and from positions labeled L1, L2, L3 on the left hemisphere and R1, R2 and R3 on the right hemisphere (Fig. 1). L1 and R1 refer to the left and right mastoids, respectively. L2(R2) and L3(R3) were placed equidistantly on an imaginary line connecting Fz to the mastoid. The reference electrode was attached to the tip of the nose. Vertical and horizontal eye movements were monitored with electrodes placed above and beside the right eye, respectively.

The EEG was amplified with a passband of 0.1–100 Hz (−3 dB points) and stored on a computer disk for off-line analysis. The analysis period was 1.4 s (sampling rate 250 Hz) including a 50-ms pre-stimulus baseline. Those EEG epochs during which activity exceeded ± 50 μV in amplitude at any of the electrodes were automatically rejected from the analysis. After averaging, the responses were digitally low-pass filtered at 30 Hz.

The amplitudes of N100 and N400 deflections of individual subjects were measured using the latency at which they reached their peak at Cz.

3. Results

3.1. Behavior

During alcohol ingestion, one of the authors was discussing with the subject who apparently enjoyed the situation; all subjects were clearly under the influence of alcohol before the beginning of the alcohol condition. The mean alcohol level was $1.3‰ \pm 0.1$ (mean ± S.D.) just before and $1.3‰ \pm 0.1$ immediately after the alcohol condition. When asked, all but one subject said that the word classification task was easier after drinking.

The number of mistakes in classifying the Finnish words increased statistically significantly from 5.0% to 6.7% ($\chi^2(1) = 6.52$, $P < 0.02$) after drinking. For English words, the increase of mistakes from 15.8% to 16.2% was not statistically significant.

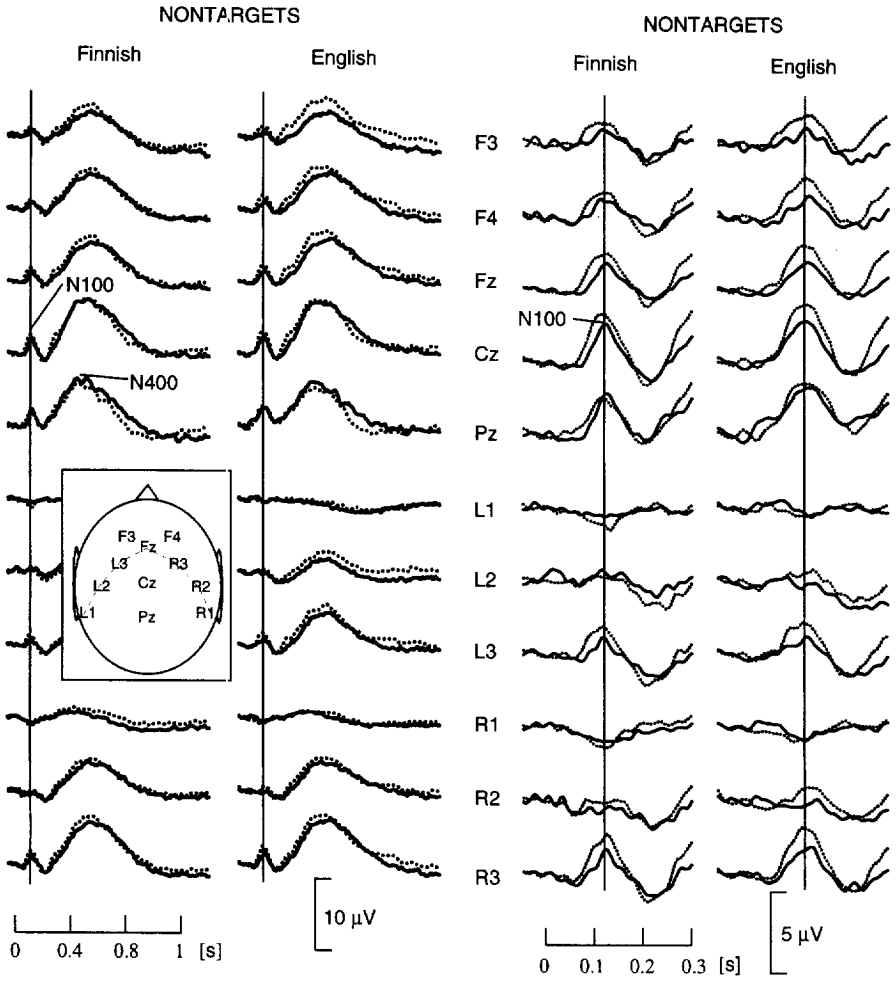

Fig. 1. Grand-average ERPs to the Finnish and English nontarget words in the control (dotted line) and alcohol (continuous line) conditions, shown on two different scales. The right side depicts the responses on more sensitive time and amplitude scales to focus on the N100 deflection. The electrode positions are shown on the schematic head.

3.2. Event-related potentials

3.2.1. The N100 deflection

The grand-average ERPs at all recorded derivations during the control and alcohol conditions for the Finnish and English non-target words are depicted in Fig. 1. The waveforms consisted of N100 and P200 deflections, followed by a slow negative N400 potential. The N100 polarity was reversed at the left and right mastoidea. N400 did not show such a polarity reversal. At most measurement locations, alcohol clearly attenuated both the N100 and N400 amplitudes.

The latencies of N100 deflections in ERPs to different stimuli in various conditions are shown in Table 1. A three-way ANOVA with the factors language, condition (alcohol, control) and concordance (target, non-target) revealed a significant main effect of language, $F_{1,8} = 13.9$, $P < 0.01$. A two-way ANOVA (language, condition) made separately for non-targets revealed a significant main effect for language, $F_{1,8} = 11.3$, $P < 0.01$. This was also the case for targets, $F_{1,8} = 6.7$,

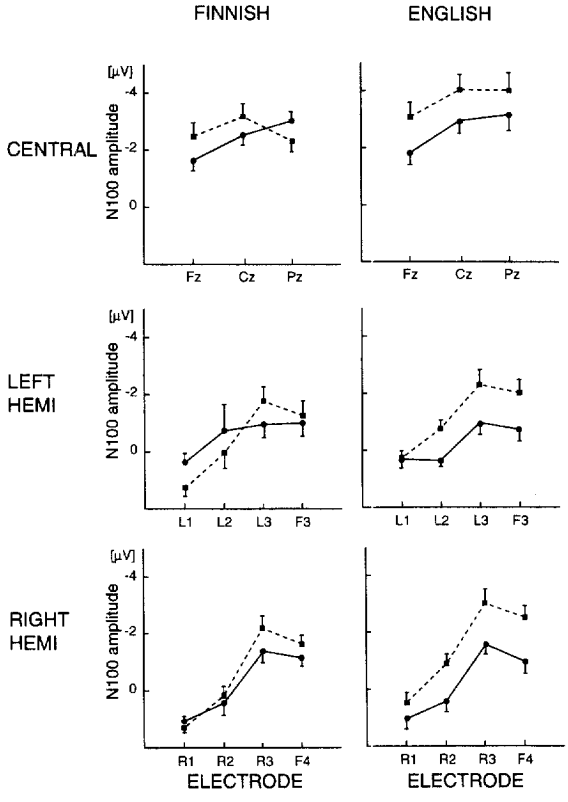

Fig. 2. The mean amplitude (±standard error of mean, SEM) of N100 deflection to the nontarget Finnish (left side) and English (right side) words in the control (squares, dashed line) and alcohol (circles, continuous line) conditions.

$P < 0.03$. A one-way ANOVA (language) for latency differences (control-alcohol) showed a significant main effect for neither non-targets nor targets.

The mean N100 amplitudes to Finnish and English non-target words at midline and over the left and right hemispheres are depicted in Fig. 2. In general, alcohol diminished N100 amplitudes for both languages. This attenuation seems to be larger for English words. Attenuation was also clearly dependent on the electrode. In both control and alcohol conditions, N100 was of the opposite polarity at Fz and at the mastoids suggesting an underlying dipolar current source in the left and right temporal areas.

A four-way ANOVA was performed for the N100 amplitude with the factors: language (English, Finnish), condition (alcohol, control), concordance (target, non-target) and central electrode (Fz, Cz, Pz). Significant main effects were found for condition $F_{1,8} = 13.7$, $P < 0.01$ and electrode, $F_{2,16} = 5.3$, $P < 0.03$. The interactions between the factors were not significant.

Table 1
The latencies (ms ± S.E.M.) of N100 and N400 deflections

	English		Finnish	
	N100	N400	N100	N400
Control				
Non-target	125 ± 4	526 ± 14	106 ± 4	494 ± 13
Target	120 ± 6	504 ± 17	108 ± 3	461 ± 26
Alcohol				
Non-target	123 ± 4	538 ± 18	116 ± 3	507 ± 15
Target	122 ± 6	542 ± 22	112 ± 4	482 ± 19

A four-way ANOVA with the same factors as above was applied separately for the left and right hemisphere electrodes (see Fig. 2). On the left hemisphere, the main effect of electrode was significant, $F_{3,21} = 9.7$, $P < 0.01$ as was the interaction of condition and electrode, $F_{3,21} = 8.9$, $P < 0.01$ and the interaction of language, condition and concordance, $F_{1,7} = 12.0$, $P < 0.01$. On the right hemisphere, significant main effects were found for condition, $F_{1,7} = 39.6$, $P < 0.01$ and electrode, $F_{3,21} = 27.4$, $P < 0.01$. Also the interaction of condition and electrode was significant, $F_{3,21} = 6.0$, $P < 0.01$.

The above analyses showed clearly that alcohol decreases the N100 amplitude in ERPs to words. In the following analyses, N100 amplitude difference obtained by subtracting the amplitude in the alcohol from that in the control condition was used.

A three-way ANOVA (language, concordance, central electrode) revealed no significant main effects. Only the interaction of concordance and electrode was significant, $F_{2,16} = 4.6$, $P < 0.05$. Similar ANOVAs performed separately for non-targets and targets showed no significant main effects or interactions.

A three-way ANOVA was made for the left hemisphere data with the factors language, concordance and electrode (L1, L2, L3, F3). A sig-

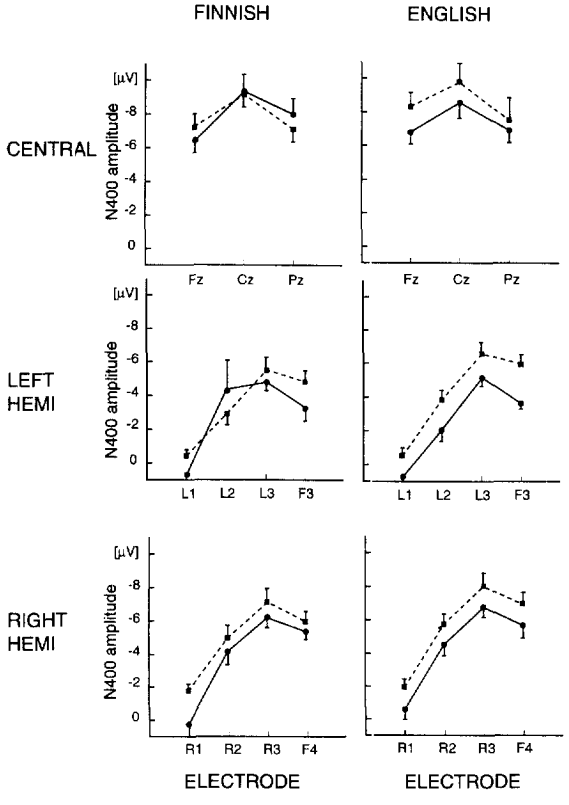

Fig. 3. The mean amplitude (± standard error of mean, SEM) of N400 deflection to the nontarget Finnish (left side) and English (right side) words in the control (squares, dashed line) and alcohol (circles, continuous line) conditions.

nificant main effect of electrode was found, $F_{3,21} = 8.9$, $P < 0.01$. The interaction of language and concordance was also significant, $F_{1,7} = 12.0$ $P < 0.01$. A two-way ANOVA (language, electrode) for non-targets showed a significant main effect of language, $F_{1,7} = 10.4$, $P < 0.01$. For targets, only a significant main effect of electrode was found, $F_{3,21} = 7.2$, $P < 0.02$).

A three-way ANOVA was made for the right hemisphere data with the factors language, concordance and electrode (R1, R2, R3, F4). A significant main effect of electrode was found, $F_{3,21} = 6.1$, $P < 0.01$. A two-way ANOVA (language, electrode) for non-targets showed a significant main effect of language, $F_{3,21} = 8.5$, $P < 0.02$ and electrode, $F_{3,21} = 6.3$, $P < 0.02$. For targets, there were no significant main effects or interactions.

The interactions in the above analyses suggest that the effect of alcohol is dependent on the electrode. Therefore, those channels (Fz, Cz, L3, R3, F3, F4) showing responses of the same polarity and a decrease after alcohol consumption to both English and Finnish words were selected to further study the language-specificity of the alcohol effect. A three-way ANOVA (language, concordance, electrode) on amplitude differences (control-alcohol) revealed neither significant main effects nor interactions. Two-way ANOVA (language, electrode) for non-targets revealed a significant main effect of language, $F_{1,8} = 6.3$, $P < 0.04$. For targets, the main effect of language was not significant. The nearly significant language-electrode interaction, $F_{5,40} = 2.9$, $P < 0.08$, suggests a trend for language-specific attenuation on some of the channels.

In summary, ANOVAS revealed a strong attenuating effect of alcohol on N100 amplitude. Attenuation was dependent on the electrode and also on the concordance of the word. For non-target stimuli, the attenuation over both hemispheres was significantly larger for English rather than for Finnish words. Such a significant effect was not found for targets. The latter result is also demonstrated in Table 2 showing the mean effect of alcohol for the English and Finnish words (percent decrease from the values in control con-

Table 2
The decrement of N100 and N400 amplitudes in alcohol compared to control condition

	English %		Finnish %
N100			
Fz	41	>	34
Cz	28	>	21
L3	60	>	47
R3	48	>	37
F3	64	>	20
F4	61	>	28
N400			
Fz	18	>	11
F3	38	>	32
F4	18	>	10
L3	21	>	12
R3	15	>	13
R2	22	>	17

dition) at selected channels. In each of the shown derivation, alcohol attenuated more N100 for English than for Finnish words.

3.2.2. N400

The mean amplitudes of N400 at different scalp locations for the Finnish and English non-target words in the control and alcohol conditions are shown in Fig. 3. There seems to be a small attenuation due to alcohol. On the right hemisphere, the attenuation can be seen for both Finnish and English words, albeit the effect seems to be slightly stronger for English words.

The latencies of N400 deflections in ERPs to different stimuli in various conditions are shown in Table 1. A three-way ANOVA with the factors language, condition (alcohol, control) and concordance (target, non-target) revealed a significant main effect for language, $F_{1,8} = 53.4$, $P < 0.01$ and condition, $F_{1,8} = 18.3$, $P < 0.01$. A two-way ANOVA (language, condition) made separately for non-targets revealed a significant main effect for language, $F_{1,8} = 10.1$, $P < 0.01$. A similar analysis for targets showed a significant main effect for language, $F_{1,8} = 14.2$, $P < 0.01$ and for condition, $F_{1,8} = 0.02$. A one-way ANOVA (language) for latency differences (control-alcohol) did show a significant main effect for neither non-targets nor targets.

A four-way ANOVA was performed for the N400 amplitude with the factors: language (English, Finnish), condition (alcohol, control), concordance (target, non-target) and central electrode (Fz, Cz, Pz). Significant main effects were found for concordance $F_{1,8} = 14.5$, $P < 0.01$ and electrode, $F_{2,16} = 12.4$, $P < 0.01$. Significant interactions were found for language and concordance, $F_{1,8} = 9.1$, $P < 0.02$, language and electrode, $F_{2,16} = 8.7$, $P < 0.01$ and condition and electrode, $F_{2,16} = 9.5$, $P < 0.01$.

A four-way ANOVA with the same factors as above was applied separately for the left and right hemisphere electrodes (see Fig. 2). On the left hemisphere, the main effect for electrode was significant, $F_{3,21} = 29.0$, $P < 0.01$, as were the interactions of language and electrode, $F_{3,21} = 4.6$, $P < 0.03$, condition and concordance, $F_{1,7} = 9.3$, $P < 0.02$ and concordance and electrode, $F_{3,21} = 7.5$, $P < 0.01$. On the right hemisphere, significant main effect was found for electrode, $F_{3,21} = 43.0$, $P < 0.01$. Significant interactions were found for language and electrode $F_{3,21} = 4.0$, $P < 0.05$, condition and concordance, $(F_{1,7} = 16.5$, $P < 0.01$, concordance and electrode, $F_{3,21} = 8.4$, $P < 0.01$ and language, condition, concordance and electrode, $F_{3,21} = 3.8$, $P < 0.04$.

A three-way ANOVA (language, concordance, central electrode) on the amplitude differences (control-alcohol) revealed a significant main effect of electrode, $F_{2,16} = 9.5$, $P < 0.01$ and no interactions. A two-way ANOVA (language, electrode) performed separately for non-targets showed a significant main effect of electrode, $F_{2,16} = 7.2$, $P < 0.01$. For targets, the main effect of electrode was also significant, $F_{2,16} = 4.1$, $P < 0.04$.

A three-way ANOVA was made for the left hemisphere data with the factors language, concordance and electrode (L1, L2, L3, F3). A significant main effect of the concordance was found, $F_{1,7} = 16.4$, $P < 0.01$. A two-way ANOVA (language, electrode) for non-targets and targets showed neither significant main effects nor interactions.

A three-way ANOVA was made for the right hemisphere data with the factors language, concordance and electrode (R1, R2, R3, F4). A significant main effect of the concordance was found, $F_{1,7} = 16.5$, $P < 0.01$. Also the interaction of language, concordance and electrode was significant, $F_{3,21} = 3.8$, $P < 0.04$. A two-way ANOVA (language, electrode) for non-targets and targets showed neither significant main effects nor interactions.

The performed ANOVAs clearly showed the main effect of the concordance, the N400 amplitudes being larger for the non-target words. The language-specific effect of alcohol, even though appearing for non-targets (See Fig. 3 and Table 2), was not significant.

4. Discussion

The present results showed that alcohol attenu-

ated the amplitude of N100 elicited by foreign rather than by native words, supporting the hypothesis presented in the Introduction. The effect was especially clear for non-targets. A similar small trend was seen for N400. The N100 and N400 latencies were shorter for Finnish than for English words. At least partly, these latency differences can be explained by differences in the acoustical features in the Finnish vs. English words. Alcohol increased the latency of N400, but this increase was not language-specific.

As indicated by the error rate, it was much more difficult to classify foreign than native words. Thus it could be argued that alcohol effects differ due to differences in task difficulty and in the amount of practice with foreign and native languages. However, Maylor and Rabbitt, (1988a,b) using a similar alcohol dose as in the present experiment, have shown that the effect of alcohol is independent on the amount of practice and on the difficulty of the word categorization task. In addition, because of the long inter-stimulus interval used in the present experiment, the differences in selective attention in control and alcohol conditions can not explain the selective alcohol effect on N100 (see Näätänen, 1992). Moreover, the number of errors in categorizing English words did not increase after drinking, suggesting that similar amounts of attention were paid in control and alcohol conditions.

The limited number of electrodes used in the present experiment allows only crude assumptions concerning the brain areas affected by alcohol. N100 to auditory stimuli consists of several subcomponents, whose neuronal generators differ (Näätänen and Picton, 1987). N100 receives a strong contribution from the supratemporal auditory cortex (Hari et al., 1980; Scherg et al., 1989); this dipolar source underlies the polarity inversion between the recordings made at the midline and at the mastoids. The amplitude reduction both at the midline (Fz) and at the left mastoid (L1) clearly seen for the Finnish words (Figs. 1 and 2) suggests that alcohol affects the processing of information at the supratemporal auditory cortex, at least in the left hemisphere. The scalp distribution of N100 for English words is rather similar to that for the Finnish words. The polarity of the responses at L2 and R2 changed from negative to positive after alcohol. This might again be due to the alcohol effect on supratemporal processing.

The present selective alcohol effect is early; its onset latency was approximately 50 ms (Figs. 1 and 2) and is therefore generated much earlier than the word is finished. As the effect is early and at least partly due to modification of the auditory-cortex activity, alcohol might have influence on the analysis of those acoustical features that determine the perception of phonemes of the language. Recent electro- and magnetoencephalographic (MEG) measurements have suggested that in the human auditory cortex there are neurons tuned to, e.g., frequency transitions and short sound duration (Aulanko et al., 1993; Pardo and Sams, 1993), which are important features in distinguishing different phonemes. This interpretation agrees with the prediction based on animal experiments that the 'age' of the neuron specialization, i.e. when they were recruited to be involved in a specific behavioral act, is the crucial factor determining alcohol effect (see Introduction). The auditory cortex is involved in learning to discriminate the phonemes of a foreign language much later than those of the mother tongue.

The selective effect of alcohol on N100 amplitude was small and non-significant for targets. This might be due to masking influence of brain processes related to pressing a reaction key that are very similar for both languages.

Alcohol tended to have a selective effect on N400 which did not show polarity inversion between the midline and the vertex, indicating that the cortical generation mechanisms of N100 and N400 are different. N400 was significantly larger for non-targets, in agreement with previous studies (see, e.g. Kutas and Hillyard, 1980; McCallum et al., 1984). The amplitude of N400 correlates with the amount of semantic incongruence (Kutas and Hillyard, 1980), indicating that it reflects neural processes underlying the semantic meaning of a word. Therefore, alcohol might have a selective effect also on the semantic processing.

Ojemann (1990) has demonstrated that separate cortical areas are activated by different lan-

guages even though identical tasks are used in testing the languages. Moreover, the fine characteristics, such as the size of the cortical area, are related to the age when the language was acquired. On the basis of these results, together with animal data about selective influence of alcohol on the 'younger' functional neuronal systems, it is suggested that in the present experiment alcohol suppressed to a greater degree those neuron populations which subserve the use of English language acquired relatively late in individual development.

The results of the present study provide supportive evidence for the proposition that 'age' of those functional neuronal systems which are involved in task performance is a crucial factor in determining the alcohol effect on ERPs. The influence of an 'age' variable most probably also plays a role in other experimental conditions.

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