Time-of-day Effects of Ethanol Consumption on EEG Topography and Cognitive Event-related Potential in Adult Males

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Abstract Time-of-day effects of ethanol consumption on EEG topography and cognitive event-related potential in adult males were studied. Ethanol (0.5 g/kg) or control drink was orally administered to nine healthy males at 10:00 and 18:00. The alpha2 amplitude was significantly lower than that of the control at 0.5, 2.5 and 4.5 hours after ethanol consumption in the morning. These effects were observed in the left hemisphere and were only found after consumption in the morning. The subjectively rated attention was significantly lower than that of the control at 0.5 and 2.5 hours after ethanol consumption in the morning and at 0.5 hours after ethanol consumption in the evening. In contrast, the search speed of serial search task and P300 amplitude was significantly lower than that of the control at 2.5 hours after ethanol consumption in the evening. These results demonstrate that effects of ethanol are dependent on time-of-day of consumption. Ethanol consumption significantly lowered the alpha2 amplitude when consumed in the morning, and lowered P300 amplitude when consumed in the evening. J Physiol Anthropol 19 (6): 249-254, 2000 http://www.jstage.jst.go.jp/en/

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Introduction

Ethanol administration is known to produce acute changes of human behavior and physiological functions. Some reports have indicated that these effects differ according to the time of day. Roehrs et al. (1992) found that the consumption of ethanol in the morning decreased sleep latency, but that consumption in the evening had no effect. Reinberg (1992) showed that the time required to perform random number addition test was longer when ethanol was consumed in the late evening. Horne and Baumber (1991) and Horne and Gibbons (1991) demonstrated that the ethanol-induced impairment of driving skills and auditory vigilance was greater in the early afternoon than in the early evening. These studies suggest that the psychological and physiological effects of drinking ethanol vary according to the time of day.

Many studies have confirmed that the consumption of ethanol affects electroencephalogram (EEG) activity. These studies were usually conducted in the morning (Ehlers et al., 1989; Lukas et al., 1989). Regarding the time-of-day effects of ethanol consumption, O’Boyle et al. (1995) reported that the consumption of ethanol in the morning and evening resulted in similar EEG activities. However, EEG activity was only recorded at one site in their study. Therefore, further study is needed to determine the time-of-day effects of ethanol consumption on EEG topography.

In the present study, the time-of-day effects of ethanol consumption on the P300 event-related potential (ERP) were also investigated, because this potential is considered to be a good indicator of human cognitive function in the areas of information processing, attention and working memory (Donchin et al., 1986; Gaillard, 1988). Ethanol consumption has been reported to decrease the P300 potential when consumed in the morning (Teo and Ferguson, 1986; Lukas et al., 1990). However, no investigations have been performed in comparing the effects of ethanol consumption on the P300 potential in the morning and evening.

The aim of the present study was to assess the time-of-day effects of ethanol consumption on EEG topography and the P300. Ethanol-induced effects on serial search task and subjective assessments of inebriety, sleepiness, fatigue and attention were also studied.

Methods

Subjects

Nine healthy, right-handed male volunteers (age: 24.3 ± 3.4 years, weight: 63.8 ± 5.8 kg) participated in this study. No subject had a history of ethanol abuse. The informed consent of all participants was obtained. Morningness-eveningness preferences were assessed using the
Japanese version of the morningness-eveningness questionnaire of Horne and Östberg (Motohashi, 1988). Subjects were neither extreme morning type nor extreme evening type. Beginning one week prior to the experiment, they were instructed to wake up at 6:30 and go to bed at 23:00 in order to synchronize their sleep-wake rhythms. Subjects were prohibited from consuming alcohol and from performing intense exercise beginning three days prior to the experiment.

**Procedure**

The experiments were performed over a period from January to March and were conducted in a sound-attenuating climatic chamber. Ethanol (0.5 g/kg body weight) and control drink were orally administered within a period of 30 minutes at 10:00 and 18:00. The administration of the ethanol and control during the morning and evening was counterbalanced. The ethanol was mixed in orange juice, while the control drink contained only orange juice.

The subjects came to the laboratory 2 hours before the consumption of the ethanol/control and were given a meal consisting bread and orange juice. One hour before the experiment, the oral temperature (clinical thermometer) and breath ethanol concentration (BEC) was taken and a subjective assessment of the subject’s inebriety, sleepiness, fatigue and attention (visual analogue scale method) was made. BEC was measured using an ethanol detector tube (Gastec No.112L. Japan). Visual analogue scale is a method in which subject is instructed to draw a vertical line on a horizontal 100-mm-long line on a sheet of paper. Scores were obtained by measuring the distance in millimeters from the left end of the line to the mark made by the subject. The subjective assessment was followed by the EEG recording and then P300 and serial search speed measurement. The serial search task required the subject to detect the number of times the letter “E” occurred in 15 lines of text, each line containing 54 random capital letters, in one minute. These measurements were repeated at 0.5, 2.5 and 4.5 hours after the consumption of the ethanol/control.

**EEG and P300 measurements**

The EEG recordings were performed with the subject’s eyes closed for one minute and open for one minute. Electrodes were placed at 13 recording sites (Fp1, Fp2, F7, Fz, F8, C3, Cz, C4, T5, Pz, T6, O1 and O2) according to the International 10–20 system and were referenced to linked earlobes. The EEG and vertical electrooculogram were recorded using a multi-channel bio-electric amplifier (Nihon-Kohden MME3116. Japan). The time constant and the high frequency cut-off was set at 1 second and 60 Hz, respectively. The EEG signals were digitized at a sampling rate of 100 Hz. A fast Fourier transformation was performed for artifact-free EEGs. Power spectra were computed for consecutive 5.12-second epochs. The number of averaging was 10.3 ± 2.3 with eyes closed and 6.6 ± 2.7 with eyes open, respectively. The mean power values were computed for the following frequency bands: 4.00–8.00 Hz (theta), 8.10–9.96 Hz (alpha1), 10.05–12.98 Hz (alpha2), and 13.08–19.63 Hz (beta1), and transformed into the amplitude values in microvolts.

The EEG topography was constructed according to the method of Ueno and Matsuoka (Ueno and Matsuoka, 1976). Briefly, the values for the non-measurement points were calculated from the measurement points and then interpolation was conducted for the values from both measurement and non-measurement points. The EEG topography was constructed by using the values after interpolation.

The P300 was recorded at Cz and elicited using an odd-ball task in which a sequence of non-target tones (1000 Hz, 70 dB SPL) and target tones (2000 Hz, 70 dB SPL) were presented at a rate of 0.5/sec. One hundred and fifty stimuli were presented, and the target tones occurred randomly with a probability of 0.20. The subject was instructed to press a key with his right hand as quickly as possible when a target tone was heard and to count the number of target tones. The reaction time to the target tones was recorded using a personal computer (NEC PC9821). The time constant and the high frequency cut-off was set at 1 second and 60 Hz, respectively. The EEG signals were digitized at a sampling rate of 500 Hz. Trails that included an EOG artifact (>150 µV) were excluded from the averaging analysis. The peak of P300 was not obtained for several subjects, so the latency of P300 was not analyzed and the mean amplitude of P300 was calculated in the 250- to 450-ms latency range.

**Statistical analysis**

Three-way (time of consumption × time after consumption × subjects) ANOVA was performed for the data of BEC, subjectively rated inebriety. Four-way (ethanol/control × time of consumption × time after consumption × subjects) ANOVA was performed for the other data. Paired t-test was also used to assess differences between ethanol and control. For EEG analysis with eyes open, eight subjects were used because there were many artifacts in one subject. Other data was from the nine subjects.

**Result**

Figure 1 shows the changes in the amplitude of EEG activity at Cz with the subject’s eyes open before and after the consumption of the ethanol/control. At Cz, a significant interactive effect between ethanol consumption and the time of consumption was only
found in the alpha2 (F=6.41; df=1,7; p<0.05) and beta1 bands (F=5.68; df=1,7; p<0.05). The alpha2 amplitude was significantly lower than that of the control at 0.5, 2.5 and 4.5 hours after ethanol consumption in the morning (*: p<0.05). Main effects of ethanol consumption, time of consumption and time after consumption were not significant for all bands. In addition to the changes at Cz, an interactive effect between ethanol consumption and the time of consumption was also observed at F7 (F=19.52; df=1,7; p<0.01) and T5 (F=17.13; df=1,7; p<0.01) for the alpha2 amplitude and at C3 (F=5.62; df=1,7; p<0.05) and T6 (F=9.15; df=1,7; p<0.05) for the beta1 amplitude. Main effects of ethanol consumption, time of consumption, time after consumption and any interactive effects were not significant for any bands at any sites when the subject’s eyes were closed.

The changes in EEG topography for the alpha2 activity when the subject’s eyes were open are shown in Fig. 2. In the morning, the alpha2 activity increased after consumption of the control, especially in the left hemisphere, but no increase was observed following ethanol consumption. In the evening, no differences were found between the control and the ethanol.

Figure 3 shows the changes in search speed and P300 amplitude before and after the consumption of the ethanol/control. The search speed and P300 amplitude were significantly lower at 2.5 hours after ethanol and control consumption. Compared to the results for control consumption, search speed and P300 amplitude were significantly lower at 2.5 hours after ethanol consumption in the evening (*: p<0.05). Data is shown as the mean ± S.E.
consumption, time after consumption and any interactive effects were not significant in P300 amplitude. Main effects of ethanol consumption, time of consumption, time after consumption and any interactive effects were not significant in reaction time to the target tone.

Figure 4 shows the changes in subjectively rated sleepiness, fatigue and attention before and after the consumption of the ethanol/control. Ethanol consumption had a significant effect on subjectively rated attention (F=17.74; df=1,8; p<0.01). The subjectively rated attention at 0.5 and 2.5 hours after ethanol consumption in the morning and at 0.5 hours after ethanol consumption in the evening was significantly lower than that of the control. Main effects of ethanol consumption, time of consumption, time after consumption and any interactive effects were not significant in subjectively rated sleepiness and fatigue.

Figure 5 shows the changes in BEC and subjectively rated inebriety before and after the consumption of the ethanol. Both BEC and subjectively rated inebriety reached a peak at 0.5 hours after consumption and then decreased, regardless of the time of day. Significant main effects of time after consumption were observed in both the BEC (F=36.12; df=2,16; p<0.01) and the subjectively rated inebriety (F=18.58; df=2,16; p<0.01). Neither significant main effects of time of consumption nor significant interactive effect between time of consumption and time after consumption was found on the BEC or the subjectively rated inebriety.

Discussion

The present study shows that the alpha2 amplitude after ethanol consumption in the morning was significantly lower than that of the control when the subject’s eyes are open, but this effect was not observed when ethanol was consumed in the evening. This result confirms that the effects of ethanol on EEGs are dependent on time-of-day consumption. It is known that alpha2 power increases in the morning and reaches a peak in the afternoon (Cacot et al., 1995). O’Boyle et al. (1995) reported that the relative alpha2 power was lower than that of the control after ethanol consumption during both morning and evening, and that the differences between morning and evening were not significant. These results are inconsistent with ours. This inconsistency seems to be related to the control of the subject’s sleep-wake rhythm. O’Boyle et al. (1995) mentioned that the sleep-wake rhythm was not sufficiently controlled in their subjects.

The effects of ethanol on sleep latency have been reported to differ for morning and evening consumption (Roehrs et al., 1992). Ethanol consumed in the morning decreases sleep latency but has no effect when it is consumed in the evening. Our results show a significant
effect of ethanol on EEG activity only in the morning and are thus consistent with the study of Roehrs et al. (1992). However, these time-of-day effects were not observed for the subjectively rated sleepiness. Similar time-of-day effects of ethanol consumption were observed for the subjectively rated attention. The effects of ethanol consumption on subjectively rated attention were greater in the morning than in the evening. Thus, the effect of ethanol on the alpha2 amplitude appears to be related to a decrease in subjectively rated attention, rather than sleepiness.

A few reports studying the localization of ethanol effects on EEG power have been conducted. These studies were conducted at a certain time of day, and no consistent results have been found (Ehlers et al., 1989; Lukas et al., 1990; Stenberg et al., 1994). In the present study, no increase of the alpha2 activity was found following ethanol consumption and this effect was mainly located in the left hemisphere. This left-dominant effect after ethanol consumption has been previously reported (Stenberg et al., 1994). However, the present study demonstrates that this effect is only found in the morning. Time-of-day effects should thus be considered when assessing the effects of ethanol consumption on EEG topography.

Contrary to the EEG and subjectively rated attention findings, the P300 amplitude and the search speed were lower than those of the control when ethanol was consumed in the evening. The P300 is known to be associated with cognitive function and information processing. The P300 amplitude usually decreases after ethanol consumption (Teo and Ferguson, 1986; Rohrbaugh et al., 1987; Michel and Battig, 1989; Grillon et al., 1995), but no investigations have been conducted on the time-of-day effects of ethanol on the P300. In the present study, a decrease in the P300 amplitude was only found when ethanol was consumed in the evening, suggesting that the P300 amplitude is more vulnerable to the depressive effects of ethanol in the evening. Ethanol-induced effects on search speed were similar to those for the P300 amplitude. Search speed in the present study significantly decreased only when ethanol was consumed in the evening. This result is consistent with previous studies on performance (Rutenfranz and Singer, 1967; Lutz et al., 1991; Reinberg, 1992).

The present study confirms the time-of-day depressive effects of ethanol on brain activity and behavior in adult males. Moreover, these time-of-day effects of ethanol consumption vary according to the psychological and physiological variables that were measured. The time of day should therefore be taken into account when assessing the effects of ethanol consumption.

In conclusion, time-of-day effects of ethanol on brain activity and performance were confirmed in adult males. Compared to those of the control, the alpha2 amplitude and subjectively rated attention were significantly lower when ethanol was consumed in the morning while P300 amplitude and search speed were significantly lower when ethanol was consumed in the evening.

References


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