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Separate and combined psychophysiological effects of cigarette smoking and alcohol consumption

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Abstract. The present study on the separate and the combined effects of cigarette smoking and alcohol consumption on behavioral, electrocortical and cardiovascular functions involved 20 young female smokers, repeatedly tested on their performance in a visual information processing task before and after drug treatment. Each subject participated in four sessions where they received in a balanced sequence 0.7 g/kg alcohol or placebo followed by either real or sham smoking of a cigarette. The mental task required the subjects to detect sequences of three odd or even digits in a pseudorandom series of single digits presented on a TV screen. By using a variable subject-paced interstimulus interval, mental performance was analyzed continuously in terms of the achieved processing rate. The multivariate assessment of psychophysiological functions included the electrocardiogram, the finger plethysmogram and the electroencephalogram (EEG) measured on four electrode locations (Fz, Cz, P3, P4). The EEG was analyzed both for tonical changes in frequency distribution and for phasic responses to the correctly detected triads (Event-Related Potentials, ERP), yielding a CNV after the second digit and a late positive wave (LP) after the third digit. Cigarette smoking increased the processing rate, while it was decreased by alcohol. Smoking after alcohol diminished the performance decline due to alcohol. Heart rate acceleration and peripheral vasoconstriction were observed after smoking. Alcohol caused dilatation of the finger vessels which was prevented by smoking a cigarette after the drink. Electrocortically, smoking caused an increase in power and maximal frequency within the beta range of the tonic EEG while the ERP analysis revealed topographical changes in N1 and LP and a reduction of the CNV. These effects, which were not observed when drinking alcohol before smoking, suggest a relation of these changes to the increased stimulus processing ability. Alcohol on the other hand caused an increase in alpha power and a decrease in the LP magnitude, which might reflect the deteriorated cognitive performance after this drug.

Key words: Information processing – EEG – Event-related potentials – Heart rate – Smoking – Alcohol

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Several epidemiological studies revealed higher smoking rates among heavy drinkers than among nondrinkers (for a review see Istvan and Matarazzo 1984). Laboratory experiments demonstrated that alcohol increases the amount and rate of cigarette smoking (Griffiths et al. 1976; Mintz et al. 1985). Nil et al. (1984) found that a cigarette was smoked with increased CO absorption after an alcohol-containing beverage as compared to a placebo beverage.

The mechanisms which are possibly involved in the relationship between these two drugs are still unclear. As recently confirmed by Benowitz et al. (1986), there is hardly any evidence that either one of the two drugs might affect clearance or metabolic rate of the other one. On the other hand, the two drugs produce opposing psychopharmacological effects on several functions, among which those on cognitive and attentional performances as well as those on electrocortical activity have received particular attention in previous research. Smoking or nicotine was predominantly found to stimulate electrocortical activity (for reviews see Conrin 1980; Edwards et al. 1985) and mental performance (reviewed by Wesnes and Warburton 1983).

Ethanol on the other hand appears to depress both electrocortical activity (e.g., Campbell et al. 1984; Lukas et al. 1986; Teo and Ferguson 1986) and mental performance in a dose-related fashion (e.g., Baker et al. 1985; Gustafson 1986).

Although such studies favor the concept that interactions between smoking and drinking alcohol might be due to an at least partially antagonistic action on the CNS level, up to now only very few studies have investigated the combined CNS effects of the two substances and these yielded contradictory results: Leigh (1982) found that alcohol-induced increased critical flicker fusion threshold (CFF) was antagonized by smoking, and Tong et al. (1974) reported antagonistic effects of the two drugs on two-flash fusion (TFF). On the other hand, no interactive effects were found by Jubis (1986) on free recall of relevant cues or by Knott and Venables (1980) on reaction time.

The present study was designed to investigate the separate and combined effects of ethanol and cigarette smoking on continuous rapid information processing. This task was presented pre- and post-treatment and the set of assessed variables included continuous recording of the pulse rate, of the acrodermal circulation and of the EEG, the latter being used to analyze both the event-related potentials in

connection with the information processing task and the frequency-related power analysis for selected periods.

Method

Subjects

Twenty female smokers (age range 18–30 years) were selected for this study. They had a mean smoking history of 7.7 years (range 1–17 years) and an average cigarette consumption of 18.8 (±8.6) cigarettes/day. All of them participated in an earlier study where the effects of nicotine chewing gums were examined (Michel et al. 1988). They were therefore familiar with the laboratory situation and highly trained with respect to the mental task. The subjects were required to abstain from tobacco, beverages and food for at least 2 h prior to the laboratory session which started between 10:00 and 12:00 a.m. and lasted about 3 h. The volunteers were paid for their participation, including an additional reward based on their performance.

Treatments

Each subject participated in four sessions and received each of the following treatments in a balanced sequence:

a) Alcohol (0.7/g/kg) + Cigarette smoking
b) Alcohol (0.7 g/kg) + Sham smoking
c) Placebo beverage + Cigarette smoking
d) Placebo beverage + Sham smoking

Gin flavoring and 96 vol% ethanol were mixed and diluted with orange juice to yield a 15 vol% ethanol beverage. The placebo beverage consisted of an equal volume of orange juice with gin flavoring and 3–5 ml ethanol floated on the surface. Blood alcohol concentration (BAC) was assessed before, 15 min after the beverage and at the end of the session with a breath alcohol analyzer (ATC1, Joma Trading AG). In the cigarette smoking conditions, the probands were allowed to smoke their own cigarette 15 min after the beverage through a cigarette holder. The cigarettes had a mean nicotine yield of 0.92 mg (±0.29) and a mean tar yield of 11.8 mg (±5.2). Expiratory tidal air CO was assessed before smoking and at the end of each session using the Ambient CO Monitoring system (Model 866 Beckman Instruments Inc.) as described earlier (Nil et al. 1984; Woodson et al. 1987). In the sham smoking condition, the subjects were puffing the unlit cigarette.

Mental task

Mental performance of the subjects was measured with a visual rapid information processing task (VRIP) as described earlier (Bättig and Buzzi 1986; Michel et al. 1987). The task required the volunteers to attend to single digits (1 to 8) presented for 80 ms on a TV monitor (width: 6 cm, height: 9 cm, yellow on blue background, distance: 2.5 m). The task was to detect triads of either odd or even consecutive digits and to respond as quickly as possible by pressing a button. A fixed pseudorandom sequence of 250 digits, including 11 triads of odd and 12 triads of even digits, was repeatedly delivered to the subjects throughout a trial. The frequency of digit presentation was initially set at 100 per min and was subsequently adapted to the actual performance by increasing the interdigit intervals after each error and by decreasing it after each correct response in steps of 40 ms. The program allowed a maximal rate of 300 digits per minute and a minimum of 30 digits per minute.

Procedure

After arriving at the laboratory the subjects were fitted with the electrodes and the calibration signals were recorded. Then the subjects had to fill out questionnaires concerning personal data, life style and smoking behavior and the breath alcohol level was assessed. The session then started with an initial 5-min resting period (eyes open) followed by a pretreatment VRIP trial of 20 min duration. Then the subjects received the beverage without information about the alcohol content. They were required to drink the beverage within 10 min. After a pause of 15 min, BAC and CO level were assessed. Smoke need was asked before the subjects were allowed to smoke (real or sham). Immediately after finishing the cigarette a second relaxation period of 5 min duration was required which was followed by the post-treatment 20 min VRIP trial. A last 5-min relaxation period was recorded before the last measures of BAC and expiratory CO.

Recordings

EEG. Goldcup electrodes were fixed to Fz, Cz, P3 and P4 (international 10/20 system) sites, referred to the linked earlobes. A bipolar montage between the infraorbital and supraorbital ridge of the left eye was used to monitor eye movements. The signals were amplified with bandpasses from 0.2 to 25 Hz, digitized at a rate of 125 cps, and recorded on magnetic tape using the PCM digitization method (Johne and Reilhofer Ltd).

Additionally, digitally coded signals (1 ms resolution) were recorded on the tape for the identification of the type and onset of the stimuli and the button presses.

ECG. The electrocardiogram was recorded with Beckman Ag/AgCl electrodes fixed at aVR, V5–V6. The R-wave peaks of the ECG were detected using an ECG Cardiometer (Cardiotronics AG, Stockholm) and recorded with a separate real-time unit (1 ms resolution) of the PCM system.

Plethysmogram. Miniature photosensors (STRT-80) were placed at the palmar surface of the distal phalanx of the middle finger of the non-dominant hand. Bandpasses were set at 0.6–25 Hz and the amplified signal was continuously stored on the PCM tape.

Puff analysis. A cigarette-holder puffing flowmeter was used to obtain analogue signals for puffing flow and puffing pressure (Projects CGC Ltd, Tewkesbury, UK). A puffing analyzer was connected with the puffing flowmeter for delivering puff-by-puff digital printouts for the six parameters: puff volume, puff duration, peak pressure, latency to peak pressure, peak flow, and the interval from the preceding puff. A detailed description of these methods can be found in Bättig et al. (1982).

Data reduction

The PCM-stored data were read offline into a PDP11/34 laboratory computer and reduced to the following parameters:

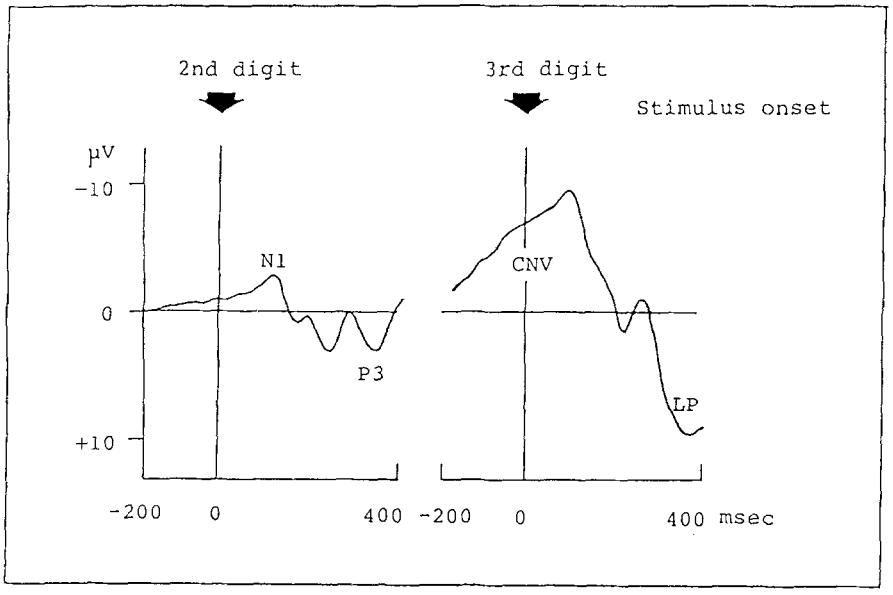

Fig. 1. Grand mean ERPs to the second and third digits of the correctly detected stimulus triads. Electrode position: *Cz*. The ERPs are averages of all subjects and all sessions

– 5-min mean values for the intervals between two R-peaks of the ECG.
– 5-min mean values for the finger pelthysmogram amplitudes.
– 10-min mean values for the stimulus processing rate (number of digits per minute) and for the concomitant reaction times.
– The EEG activities of each channel during the 5-min relaxation periods were used for power spectral analysis using a Fast Fourier Transformation (IMSL subroutines). The mean power values and peak frequencies were quantified for the frequency bands delta (1–4 Hz), theta (4–7 Hz), alpha (7–14 Hz) and beta (14–25 Hz).
– The EEG recordings during the VRIP trials were used for computing event related potentials (ERP) to the second and third digits of the correctly detected triads. A detailed description of the ERPs to the different stimuli and conditions was reported earlier (Michel et al. 1987, 1988). The averaging period lasted from 200 ms before to 400 ms after stimulus onset. The EEG epochs with corresponding ISIs shorter than 400 ms or which included eyeblinks or saturated the a/d converter were rejected. The ERPs included 40 averaged EEG epochs within both a first and a second 10-min phase of each VRIP trial. Technical zero was used as baseline.

ERP analysis

The grand mean ERPs of Cz to the second and third digits of the correctly detected triads are shown in Fig. 1. Two components were assessed from the second digit ERPs within pre-selected time ranges:

– N1 (70–155 ms) which is assumed to reflect early stimulus attention.
– P3 (260–400 ms) as a measure of stimulus categorization without motoric response.

Four measures were determined for both components:

1. The latency which was defined as the time point of maximal voltage at any of the four scalp locations, measured from technical zero baseline (Lehmann 1986).
2. The maximal potential value at the defined latency.
3. The anterior-posterior location along the scalp midline after estimating Pz voltage by computing the mean ERP of P3 and P4.
4. The voltage difference between the right and left parietal electrode locations (P3–P4).

The ERPs of the third digits were characterized by an initial negative voltage shift and a late positive voltage shift. The negative shift, which is comparable to the CNV in the S1–S2 paradigms (Rockstroh et al. 1982), reflects the expectancy to the third digit, whereas the late positive shift (LP) indicates the brain processes associated with the response selection (Donchin et al. 1978). Both components showed no clear peak within the given time window (see Fig. 1) and were therefore determined as area values between −100 to +100 ms for the CNV and between 300 and 400 ms for the LP, measured from technical zero. Total voltage, anterior-posterior location and right-left voltage differences were computed for these two area measures.

Statistics

The descriptive statistical analyses of the data were made by $4 \times 2 \times 2$ (resp. $4 \times 5 \times 2$ for the cardiovascular data) repeated measures Analyses of Variance (ANOVA, BMDP2V) with the factors A: treatment conditions (4 levels) B: development within the trials (2 or 5 levels) and C: comparison of the pre- and post-treatment trials (2 levels). Greenhouse-Geisser corrections were applied in those analyses where appropriate. Since the study attempted to investigate the psychophysiological effects of the different treatment conditions, further analyses of local contrasts were done only when the overall ANOVAs revealed either significant treatment effects or $A \times C$ interactions. In those cases post hoc analyses (Newman-Keuls, program ONEWAY, SPSS) for the single periods were performed. This

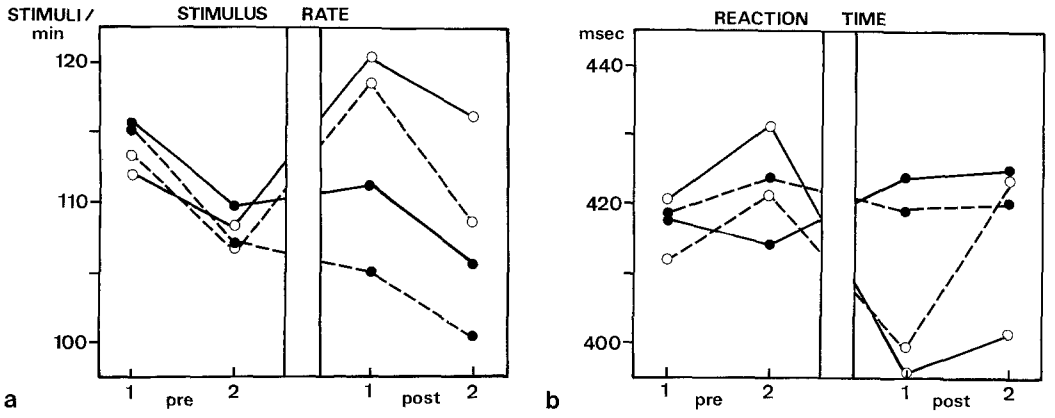

Fig. 2a, b. Performance effects. Five-minute mean values of **a** the stimulus rate and **b** the reaction time before (*pre*) and after (*post*) the four treatments. The vertical bars indicate the treatment period. Symbols: ●—● alcohol (0.7 g/kg) + real smoking; ●---● alcohol (0.7 g/kg) + sham smoking; o—o placebo beverage + real smoking; o---o placebo beverage + sham smoking

second step is chosen only in order to estimate and describe the strength of the effects of the single treatments.

Results

Drug absorption

The average BAC measured 15 min after the drink reached a mean value of 0.49‰ (±0.13) for both alcohol conditions and decreased to 0.43‰ (±0.12) for the measurements taken at the end of the sessions. CO uptake reached a mean value of 2.6 ppm (±1.7) after the two real smoking conditions. For both measurements, BAC and CO uptake, the values for the combined treatment condition did not differ from those for the separate treatments. However, a correlation between CO uptake and BAC was found in the combined treatment condition ($r=0.42$, $P=0.03$) and smoke need as well as smoke satisfaction tended to be greater after alcohol than after placebo but without reaching significance.

None of the averages of the six puffing variables differed significantly between the alcohol and no alcohol condition as compared by *t*-tests.

The data of the questionnaires were checked for the menstrual phase of the subjects. It revealed that three of the subjects had their menstruation during the combined-treatment session and four during the alcohol-without-smoking session, so that an unilateral influence on one of the two alcohol sessions can be excluded. Contraceptives were taken by 14 of the 20 subjects.

Performance effects

Figures 2a and 2b show the 10-min mean values of the stimulus processing rate (no. of digits/minute) and the reaction time to the third digit of the correctly detected triads.

Figure 2a shows an overall within trial decrease in stimulus rate [Factor B: $F(1, 19)=11.3$, $P<0.01$]), presumably as an effect of fatigue. While the subjects performed the task similarly in all pretreatment trials, the different treatments did clearly affect the performance in the post-treatment trials, which was expressed by an overall treatment × pre-post interaction [A × C: $F(3, 57)=3.6$, $P<0.01$]. The figure indicates that this effect was due to an increase in the processing rate after smoking and a decrease after alcohol. This alcohol-induced performance decrease was diminished when the subjects smoked after the beverage. The post hoc analyses of the two post-treatment values revealed significant differences between smoking and the two alcohol conditions for the first 10-min values and between smoking and all other conditions for the second 10-min values, which indicate an absolute performance increase after smoking as well as a diminished performance decline within the post-treatment trial. After the alcohol treatment without smoking the stimulus processing rate was significantly lower as compared to control in the first 10 min after the treatment.

A significant treatment × pre-post interaction was also found for the overall ANOVA of the reaction time [$F(3,57)=7.3$, $P<0.001$]. The reaction time was significantly shortened after cigarette smoking as compared to the control treatment in the second 10 min after the treatments. This shortening of the reaction time was completely suppressed when smoking was preceded by alcohol. The post hoc comparison revealed significant differences between the two alcohol and the two placebo sessions in the first 10 min after the treatments.

ERP effects

Out of the different parameters which were assessed from the event related potentials to the second and third digits of the correctly detected triads, the overall ANOVAs revealed significant treatment effects for four measures:

1. The anterior-posterior location of N1 [treatment × pre-post interaction: $F(3,57)=2.8$, $P<0.05$].
2. The anterior-posterior location of the late positivity [treatment × pre-post × within interaction: $F(3,57)=5.6$, $P<0.01$].
3. The total voltage of the late positivity [treatment × pre-post interaction: $F(3,57)=3.2$, $P<0.05$].
4. The total voltage of the CNV area [treatment effect: $F(3,57)=3.0$, $P<0.05$].

The development of these measures is shown in Fig. 3a–d.

Figure 3a shows the location of maximal negative voltage for the N1 component along the midline positions (Pz is interpolated from the positions P3 and P4). The figure shows an anterior shift of N1 in the first 10 min after ciga-

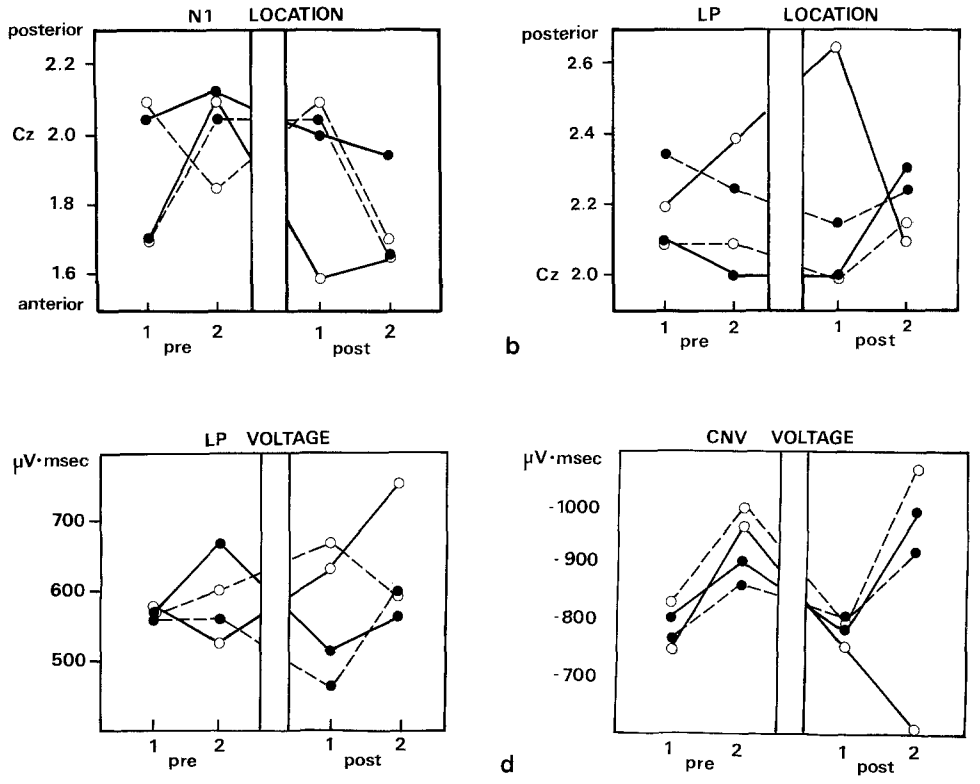

Fig. 3a–d. ERP effects. Ten-minute mean values before (*pre*) and after (*post*) the treatments. **a** Location of maximal negative voltage for the N1 amplitude after the second digit along the midline positions. *1*=Fz, *2*=Cz, *3*=Pz (interpolated from P3 and P4). **b** Location of maximal positive voltage for the LP area (300–400 ms after the third digit). *1*=Fz, *2*=Cz, *3*=Pz (interpolated from P3 and P4). **c** Total voltage of the LP area, averaged over all electrode locations. **d** Total voltage of the CNV area (100 ms before to 100 ms after the third digit), averaged over all electrode locations. The symbols are the same as in Fig. 2

rette smoking which was significant in comparison to the control session. No anterior shift was found when the cigarette was preceded by alcohol.

Figure 3b shows the location of maximal positive voltage for the area of the LP component. Maximal voltage shifted towards the posterior electrodes in the first 10 min after cigarette smoking. The location was significantly more posterior than for all other treatment conditions. The consideration of only the two posterior electrodes revealed that the maximal voltage after smoking was significantly larger on the left parietal site than after the other treatments.

Figure 3c shows the total voltage averaged across the four electrode positions for the late positive area value. The significant interaction in the overall ANOVA seems to be due to a decrease in the magnitude after alcohol, since a significant difference was found between the alcohol (without smoking) and the control session in the first 10 min after the treatment.

Figure 3d shows the total voltage for the CNV area value. It shows a clear CNV decrease from the first to the second 10 min after smoking without alcohol. This "paradoxical" development was neither observed before the treatments nor after the treatments in any of the other sessions. The effect was statistically supported by a significantly lower CNV voltage in the last 10 min after smoking as compared to all other treatments.

Effects on the resting EEG

Mean power and maximal frequency of the four EEG bands were analyzed during the three 5 min resting phases. The overall ANOVAs for these measures included the factors treatment (4 levels) and repetition (3 levels) with an additional factor for the values of the four electrode positions.

Significant treatment × repetition interactions were found for alpha power [$F(6,114)=2.3$, $P<0.05$], for beta power [$F(6,114)=2.5$, $P<0.05$] and for the maximal frequency in the theta band ($F(6,114)=2.9$, $P<0.01$], while a treatment × electrode interaction was found for the maximal frequency in the beta band [$F(9,171)=2.5$, $P<0.01$].

Figure 4a shows the development of the maximal theta frequency for the two treatment conditions, averaged over all leads. The figure shows increases of frequency after all treatments as compared to the control session. The increase was strongest for the combined treatment condition which was supported by a significant differentiation between the combined and the control treatment for the first post-treatment values.

Figure 4b shows in the same way the mean values for alpha power. The figure shows the strongest increase in alpha power after both alcohol treatments, with significantly larger values as compared to the control for the last resting period. Smoking without alcohol did not significantly differ from the control session.

On the other hand, beta power, which is shown in Fig. 4c, increased most strongly after both smoking conditions in the first resting period after the treatment (Newman-Keuls $P<0.05$ in comparison to both sham smoking conditions). For beta frequency the overall ANOVA revealed a significant lead × treatment interaction. Therefore additional 4×3 ANOVAs were performed for the single electrode positions. These analyses resulted in a significant

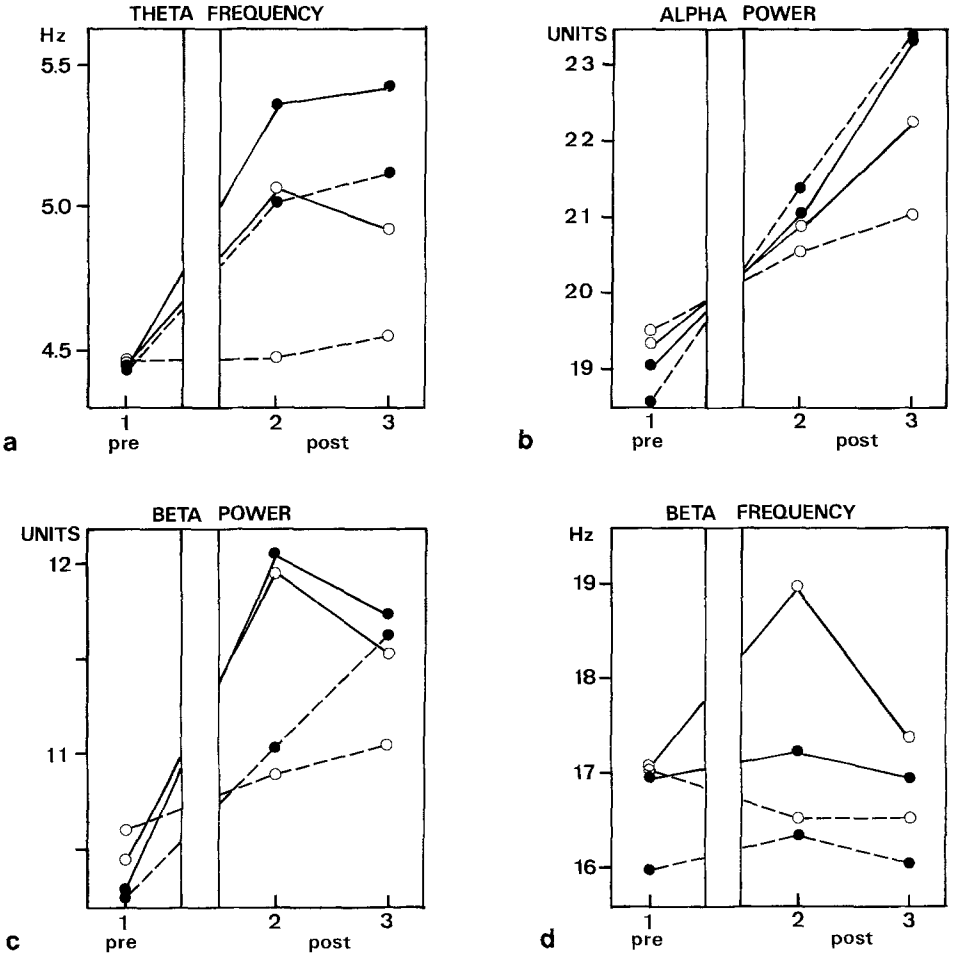

Fig. 4a–d. EEG effects. Mean power and maximal frequency of the Fourier transformed EEG measured during the 5-min resting periods. Pre 1 was assessed at the beginning of the sessions, post 2 directly after the treatments, and post 3 at the end of the sessions. **a** Maximal theta frequency (4–7 Hz), averaged over all leads. **b** Total alpha power (7–14 Hz), averaged over all leads. **c** Total beta power (14–25 Hz), averaged over all leads. **d** Maximal beta frequency for the Cz electrode location. The symbols are the same as in Fig. 2

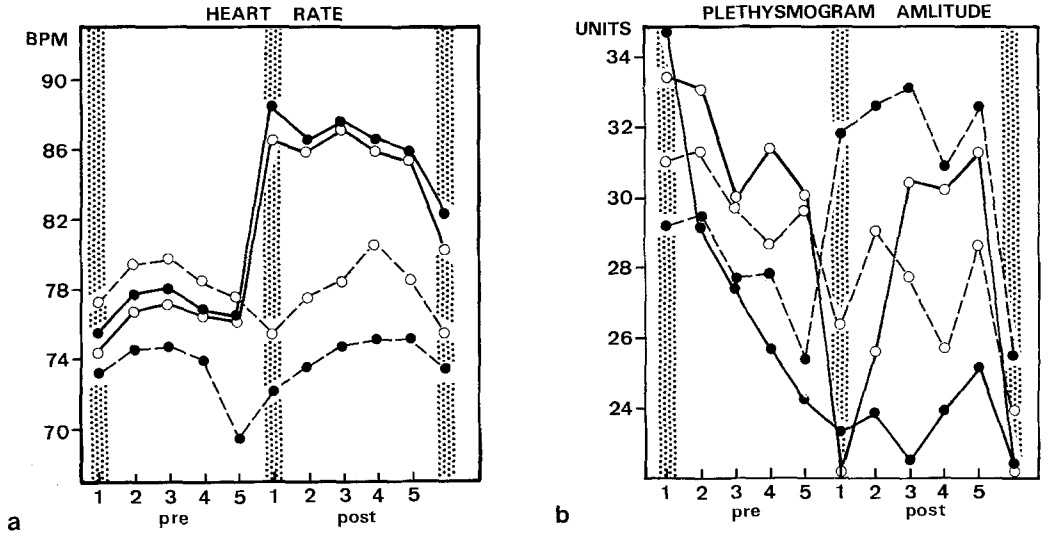

Fig. 5a, b. Cardiovascular effects. Five-minute mean values of **a** the heart rate (beats per min) and **b** the finger plethysmogram before (*pre*) and after (*post*) the four treatment conditions. The *hatched areas* represent the values measured in the resting phases. The symbols are the same as in Fig. 2

treatment effect for the central electrode position [$F(3,57) = 5.9$, $P < 0.001$]. For this electrode position the post hoc analysis also revealed significantly higher maximal beta frequency in the first values after smoking (without alcohol) than after both sham smoking conditions. The development of beta frequency for the Cz electrode is shown in Fig. 4d.

Cardiovascular effects

Figures 5a and 5b show for the four treatment conditions the development of the 5-min mean values of heart rate and of the finger plethysmogram amplitude.

For heart rate a significant treatment × pre-post interac-

tion was obtained in the overall ANOVA [$F(3,57)=34.3$, $P<0.0001$]. Considering Fig. 5a, it can be seen that smoking a cigarette was followed by a heart rate increase independent of having ingested alcohol before smoking or not. The post hoc analyses for the single periods revealed significant differences between these two real smoking conditions and the two sham smoking conditions for all post-treatment periods, including the values measured during the resting periods. The alcohol beverage (without smoking) did not influence heart rate as compared to the control treatment condition.

The overall ANOVA for the plethysmogram amplitude revealed a significant treatment × pre-post interaction on the 0.05 level [$F(3,57)=2.8$]. Figure 5b shows large intersession variabilities even before the treatments which might account for this interaction. However when comparing the last values before the treatment (pre-4) with the first post-treatment values a vasoconstriction after smoking (without alcohol) and a vasodilatation after alcohol (without smoking) can be observed. These opposing effects led to a significant difference between these two conditions in the comparisons of the first values after the treatments. The effect was antagonized in the combined treatment condition where no difference was observed between the values measured directly before and after the treatments.

Discussion

Separate effects

Smoking. Cigarette smoking enhanced performance of the RVIP task by increasing the stimulus processing rate as well as by decreasing the reaction time. These effects are in line with previous reports and are often explained by the activating effects of nicotine (for a review see Wesnes and Warburton 1983). However, considering the fact that no performance increase was observed after the treatment of the same subjects with a 4-mg nicotine gum in a completely comparable situation (Michel et al. 1988), and the finding that high and low inhaling subjects showed comparable performance increases after smoking (Michel et al. 1987; Nil et al. 1988) suggests that nonpharmacological aspects of cigarette smoking might also contribute to this performance effect.

The facilitating effects of smoking on information processing in this task were accompanied by rather selective effects of smoking on the electrical brain potentials that were related to the correctly detected stimulus triads:

The maximal amplitude of the N1 component shifted towards the frontal electrode after smoking. Since N1 is related to attentional processes (Picton and Stuss 1980; Duncan-Johnson 1981), this effect might indicate increased concentration and attention in frontal cortical regions.

The late positivity (LP) after the imperative stimuli, which was only pronounced before the motoric response (Michel et al. 1987), shifted towards the left parietal electrode. In oddball detection paradigms, P300 is detected more parietally with increasing task requirements (Hermanutz et al. 1981; Rösler et al. 1985). The shift of maximal LP voltage to this region after smoking might therefore be an index of more efficient stimulus categorization as well as of increased reaction speed.

The CNV between the second and third digits decreased within the postsmoking trial independent of the electrode location. A series of studies on the smoking effects on the CNV have shown that the CNV can be affected in both directions depending on personality characteristics and on the initial arousal state (Ashton et al. 1978; Binnie and Comer 1978; Tecce et al. 1978; Eysenck 1985; O'Connor 1986). Ashton et al. (1978) showed that intravenous injections of different doses of nicotine also caused biphasic effects on the CNV, which increased with low doses but progressively decreased with high nicotine doses. This finding and the fact that we also found a CNV reduction in this VRIP task after the treatment of a 4-mg nicotine chewing gum (Michel et al. 1988) suggest a direct pharmacological cause for this CNV change.

The cardiovascular effects of smoking (heart rate increase and vasoconstriction) are in line with previous findings (Suter et al. 1983; Woodson et al. 1986) and might mainly be caused by the sympathomimetic action of nicotine (Armitage 1978; Henningfield 1984).

This sympathomimetic action of nicotine is also used in the literature to explain the smoking-induced activation of human EEG (e.g., Conrin 1980; Edwards and Warburton 1983). Such an interpretation might hold for the increased frequency in the theta range, which has also been demonstrated after nonsmoking nicotine uptake (Pickworth et al. 1986; Michel et al. 1988). However, the most specific effect of smoking in this study was found in the beta band, where it increased total power as well as the dominant frequency. These effects, which might indicate increased alertness, were not found after alternative routes of nicotine administration in the studies cited above, suggesting again influences of nonpharmacological factors.

Alcohol. Alcohol ingestion (without smoking) caused a deterioration in information processing by decreasing the stimulus processing rate and by prolonging the reaction time as compared to that for the control treatment. This performance decrease, probably caused by the CNS depressant effects of alcohol, supports a number of studies with different task requirements (e.g., Hartley and Coxon 1984; Baker et al. 1985; Gustafson 1986).

Considering the ERP components, alcohol decreased the magnitude of the late positivity in comparison to the other treatments. This finding is in support of previous studies reporting reduction of the P300 amplitude and increases of the P300 latency after alcohol (Roth et al. 1977; Campbell et al. 1984; Teo and Ferguson 1986). These effects were mainly interpreted as an attenuation of stimulus detection and categorization. By choosing a global measure for the LP magnitude (integral between 300 and 400 ms) and by choosing an analysis period which did not fully include the P300 component, we did not attempt to differentiate between amplitude and latency effects. Nevertheless, the decrease in the LP within the processing of the imperative stimulus (third digit) indicates an influence of alcohol on a "late" step of information processing. On the other hand, N1 and CNV were not affected by alcohol in this study. Earlier studies found alcohol effects on these components only with high ethanol dosages which were not applied in this study (Ludwig et al. 1974; Teo and Ferguson 1986).

Considering the tonic EEG, alcohol significantly increased theta frequency and alpha power. Both effects were also demonstrated by Lukas et al. (1986), who found that transient increases in alpha activity paralleled the onset of

ethanol-induced euphoria. This relaxed and free-floating state of the subjects might negatively influence the attention to the task requirements.

On the cardiovascular measures, we found a vasodilatation after alcohol but no effect on heart rate. While the dilatation of skin vessels after alcohol is a known effect (Klatzky 1987), a heart rate increase, as is reported in some studies (e.e., Benowitz et al. 1986), seems to occur only after higher alcohol doses (Lukas et al. 1986).

Combined effects

Apart from the correlation between BAC and CO uptake, alcohol did not alter smoke intake on any of the puffing parameters examined. Earlier studies most often reported that alcohol increases the number and frequency of cigarettes being smoked (e.g., Istvan and Matarazzo 1984), whereas in the present study the subjects were smoking a single cigarette only. However Mintz et al. (1985) reported larger puff volumes for the first cigarette smoked after alcohol. Since the subjects were smoking deprived for 12 h prior to the test session in that study, smoke need and smoking behavior are not comparable to the present study. In the study by Nil et al. (1984), alcohol increased CO uptake and puff volume in non-deprived smokers. One reason for the lack of such effects in the present study might be that the subjects were engaged in a very stressful situation which might have caused a maximal smoke need even without alcohol.

When the subjects were allowed to smoke a cigarette after the alcohol-containing beverage, they were able to improve the stimulus processing rate as compared to that after the alcohol treatment without smoking, and reached the same performance level as that of the control session. This result indicates that smoking antagonized the alcohol-induced performance deterioration in this task. However, this antagonistic effect was not observed for reaction time, which was similarly prolonged after both alcohol treatments as compared to the control and the smoking sessions.

The studies which are cited in the Introduction (Tong et al. 1974; Knott and Venables 1980; Leigh 1982; Jubis 1986) might suggest that interactions between alcohol and smoking occur rather at the perceptual-sensory than at the cognitive or psychomotor level of information processing. This limitation of interactive effects on the information processing pathway might be partially supported by the ERP data of this study: neither of the three ERP effects observed after smoking (topographical changes of N1 and LP and CNV reduction) were found when alcohol preceded the cigarette. Since these effects, especially the topographical changes in N1 and LP, were interpreted as reflecting improvements in cognitive information processing, one might suggest that these "cognitive effects of smoking" were not the reason for the prevention of the alcohol-induced decrease in stimulus processing accuracy. On the other hand, the decrease in the LP component, which was observed after alcohol, was prevented when the subjects subsequently smoked a cigarette. As discussed in the former section, the decreased LP voltage after alcohol might be interpreted as a decrease in amplitude and/or an increase in latency of the P300 component. At any rate, smoking seemed to prevent the alcohol-induced deterioration of stimulus categorization which is reflected in the LP component.

Moreover, the data indicate increased activation of the subjects on the cardiovascular and cortical levels when they smoked a cigarette after alcohol compared to when they did not. This increased activation was expressed by a heart rate acceleration as well as by increased beta power and reduction of the alcohol-induced alpha increase. Since increased arousal (if not excessive) is suggested to reduce distraction by means of narrowing attention (Tecce et al. 1978; Jubis 1986), one might suggest that the peripheral and central activating effect of smoking in this study diminishes the depressant effect of alcohol and therefore increases alertness and cognitive ability.

Conclusion

In summary, the present study represents a laboratory demonstration that cigarette smoking after alcohol consumption diminishes the CNS depressant effects of alcohol and therefore prevents in part a mental performance decrease, a result which might be a strong reason for the increased amount and rate of cigarette smoking after alcohol consumption.

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References

Armitage AK (1978) The role of nicotine in the tobacco smoking habit. In: Thornton RE (ed) Smoking behavior: physiological and psychological influences. Churchill Livingstone, Edinburgh, pp 229–243

Ashton H, Marsh V, Millman J, Rawlins M, Telford R, Thompson J (1978) The use of event-related slow potentials of the brain as a means to analyse the effects of cigarette smoking and nicotine in humans. In: Thornton RE (ed) Smoking behavior: physiological and psychological influences. Churchill Livingstone, Edinburgh, pp 54–68

Bättig K, Buzzi R (1986) The effect of coffee on the speed of subject-paced information processing. Neuropsychobiology 16:126–130

Bättig K, Buzzi R, Nil R (1982) Smoke yield of cigarettes and puffing behavior in men and women. Psychopharmacology 76:139–148

Baker SJ, Chrzan GJ, Park CN, Saunder JH (1985) Validation of human behavioral tests using ethanol as a CNS depressant model. Neurobehav Toxicol Teratol 7:257–261

Benowitz NL, Jones RT, Jacob P (1986) Additive cardiovascular effects of nicotine and ethanol. Clin Pharmacol Ther 40:420–424

Binnie CD, Comer AK (1978) The effect of cigarette smoking on the contingent negative variation (CNV) and eye movement. In: Thornton RE (ed) Smoking behavior: physiological and psychological influences. Churchill Livingstone, Edinburgh, pp 69–75

Campbell K, Marois R, Arcand L (1984) Ethanol and the event-related evoked potentials: effects of rate of stimulus presentation and task difficulty. Ann NY Acad Sci 425:551–555

Conrin J (1980) The EEG effects of tobacco smoking – a review. Clin EEG 11:180–187

Donchin E, Ritter W, McCallum WC (1978) Cognitive psychophysiology: the endogenous components of the ERP. In: Cal-

laway E, Tueting P, Koslow S (eds) Event related brain potentials in man. Academic Press, New York, pp 349–441
Duncan-Johnson CC (1981) P300 latency: a new metric of information processing. Psychophysiology 18:207–215
Edwards JA, Warburton DM (1983) Smoking, nicotine and electrocortical activity. Pharmacol Ther 19:147–164
Edwards JA, Wesnes K, Warburton DM, Gale A (1985) Evidence of more rapid stimulus evaluation following cigarette smoking. Addict Behav 10:113–126
Eysenck HJ (1985) Stress, personality, and smoking behavior. In: Spielberger CD, Sarason IG, Dafares PB (eds) Stress and anxiety, vol 9. Hemisphere, Washington
Griffiths RR, Bigelow GE, Liebson I (1976) Facilitation of human tobacco self-administration by ethanol: a behavioral analysis. J Exp Anal Behav 25:279–292
Gustafson R (1986) Alcohol and vigilance performance: effect of small doses of alcohol on simple auditory reaction time. Percept Mot Skills 63:99–102
Hartley L, Coxon L (1984) Effect of alcohol on a sentence-picture verification task. Ergonomics 27 (2):195–203
Henningfield JE (1984) Behavioral pharmacology of cigarette smoking. Adv Behav Pharmacol 4:131–210
Hermanutz M, Cohen R, Sommer W (1981) The effects of serial order in long sequences of auditory stimuli on event-related potentials. Psychophysiology 18:415–423
Istvan J, Matarazzo JD (1984) Tobacco, alcohol, and caffeine use: review of their relationships. Psychol Bull 95:301–326
Jubis RMT (1986) Effects of alcohol and nicotine on free recall of relevant cues. Percept Mot Skills 62:363–369
Klatzky AL (1987) The cardiovascular effects of alcohol. Alcohol Alcoholism [Suppl] 1:117–124
Knott VJ, Venables PH (1980) Separate and combined effects of alcohol and tobacco on the amplitude of the contingent negative variation. Psychopharmacology 70:167–172
Lehmann D (1986) Spatial analysis of human evoked potentials. In: Cracco RQ, Bodis-Wollner I (eds) Evoked potentials. Liss, New York, pp 3–14
Leigh G (1982) The combined effects of alcohol consumption and cigarette smoking on critical flicker frequency. Addict Behav 7:251–259
Ludwig AM, Wikler A, Stark LH (1974) The first drink: the psychobiological aspects of craving. Arch Gen Psychiatry 30:539–547
Lukas SE, Mendelson JH, Benedikt RA, Jones B (1986) EEG alpha activity increases during transient episodes of ethanol-induced euphoria. Pharmacol Biochem Behav 25:889–895
Michel Ch, Nil R, Buzzi R, Woodson PP, Bättig K (1987) Rapid information processing and concomitant event-related brain potentials in smokers differing in CO absorption. Neuropsychobiology 17:161–168
Michel Ch, Hasenfratz M, Nil R, Bättig K (1988) Cardiovascular, electrocortical and behavioral effects of nicotine chewing gum. Klin Wochenschr [Suppl 11] 66:72–79
Mintz J, Boyd G, Rose JE, Charuvastra VC, Jarvik ME (1985) Alcohol increases cigarette smoking: a laboratory demonstration. Addict Behav 10:203–207
Nil R, Buzzi R, Bättig K (1984) Effects of single doses of alcohol and caffeine on cigarette smoke puffing behavior. Pharmacol Biochem Behav 20:583–590
Nil R, Woodson PP, Michel Ch, Bättig K (1988) Effects of smoking on mental performance and vegetative functions in high and low CO absorbing smokers. Klin Wochenschr [Suppl 11] 66:66–71
O'Connor K (1986) The effects of smoking and personality on slow cortical potentials recorded within a signal detection paradigm. Physiol Psychol 14:49–62
Pickworth WB, Herning RI, Henningfield JE (1987) Electroencephalographic effects of nicotine chewing gum in humans. Pharmacol Biochem Behav 25:879–882
Picton TW, Stuss DT (1980) The component structure of the human event-related potentials. Prog Brain Res 54:17–49
Rockstroh B, Elbert Th, Birbaumer N, Lutzenberger W (1982) Slow brain potentials and behavior. Urban & Schwarzenberg, Baltimore-Munich
Rösler F, Manzey D, Sojka B, Stieglitz RD (1985) Delineation of pharmacological effects by means of endogenous event-related brain potentials: an exemplification with flupentixol. Neuropsychobiology 13:81–92
Roth WT, Tinklenberg JR, Kopell BS (1977) Ethanol and marihuana effects on event-related potentials in a memory retrieval paradigm. Electroencephalogr Clin Neurophysiol 42:381–388
Suter TW, Buzzi R, Bättig K (1983) Cardiovascular effects of smoking cigarettes with different nicotine deliveries: a study using multilead plethysmography. Psychopharmacology 80:106–112
Tecce J, Savignano-Bowman J, Cole J (1978) Drug effects on contingent negative variation and eyeblinks: the distraction-arousal hypothesis. In: Lipton M, Dimascio A, Killman K (eds) Psychopharmacology: a generation of progress. Raven Press, New York, pp 745–758
Teo RKC, Ferguson DA (1986) The acute effects of ethanol on auditory event-related potentials. Psychopharmacology 90:179–184
Tong JE, Knott VJ, McGraw DJ, Leigh G (1974) Alcohol, visual discrimination and heart rate, effects of dose, activation and tobacco. Q J Stud Alcohol 35:1003–1022
Wesnes K, Warburton DM (1983) Smoking, nicotine and human performance. Pharmacol Ther 21:189–208
Woodson PP, Buzzi R, Nil R, Bättig K (1987) Effects of smoking on vegetative reactivity to noise in women. Psychophysiology 23:272–282

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