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Abstract: Verbal memory functioning was assessed in light and heavy social drinkers by administering a variety of cognitive tasks and by recording event-related potentials while subjects were instructed to memorise information using either repetition or elaborative learning strategies. Although overall performance did not differ significantly between light and heavy drinkers, a behavioural measure of the size of inter-related groups formed when subjects were required to utilise elaborative learning strategies indicated that the heavy drinkers formed smaller units than the light drinkers. There were statistically significant differences in the event-related potential indices of memory functioning elicited during complex elaborative processing which were consistent with the reduced inter-item associations.

Key words: Alcohol, social drinkers, memory, event-related potentials (ERPs)

The literature on cognitive impairments associated with the long-term effects of excessive alcohol consumption in patients seeking treatment for alcohol-related problems has been extensively reviewed. Most reviewers have agreed that these patients typically show deficits in problem-solving ability, abstracting ability and visuo-spatial processing and memory[1-6]. The deficits are more frequently apparent with visuo-spatial tasks rather than verbal tasks, although this may reflect the novelty or lack of familiarity with these materials[7].

The effects of alcohol consumption in 'social' drinkers (usually defined in terms of subjects who have not sought treatment for alcohol related problems) provides conflicting evidence. Parker and Noble[8] reported the first experiments investigating the effects of alcohol consumption on cognitive functioning in social drinkers. They reported significant correlations between level of alcohol consumption and tests of abstraction, adaptive abilities and concept formation, as measured by the Shipley-Hartford Institute of Living Scale (SILS), the Halstead Category Test and the Wisconsin Card Sorting Test (WCST). All correlations reported in this study controlled for the effects of age. Performance on the cognitive tests was related to the average quantity consumed per occasion, and not to lifetime consumption of alcohol, and they therefore suggested that social drinking may not have a strong cumulative effect on cognitive functioning, or that the lifetime measures may be inadequate. When the sample was subdivided into light and heavy drinkers, they reported correlations between the average quantity per occasion and their measures of free-recall memory and learning in the heavy drinkers only. Parker, Birnbaum, Bond and Noble[9] replicated these basic findings in a group of young college students. However, reviews of the area[10,11] have suggested that the findings reported in these two studies have been difficult to replicate. Although significant correlations between some measures of alcohol consumption and performance on various psychological tests are frequently obtained, the specific replication of a relationship between quantity per occasion and the subscales of the SILS and WCST is less frequently observed.

These conflicting findings have been attributed to a variety of causes, for example, spurious associations due to the large number of correlations carried out, the relatively weak nature of the associations or the likely presence of other confounding variables accounting for the relationship between drinking variables and test scores. The relationships observed may also depend on the age, drinking history and male/female ratios of the sample, and on the variables controlled in the analysis.

Weak relationships may also be the result of using tests which are relatively insensitive to mild cognitive impairments. Other studies investigating the effects of alcohol consumption on cognitive functioning have focussed on various aspects of memory tests which may provide more sensitive indices of those aspects of cognitive functioning which are related to alcohol consumption. Jones and Jones[12] reported significant group differences between light and moderate female social drinkers on a verbal memory task. The performance measure that showed differences in this experiment was the ratio of delayed free-recall after presentation of six word lists (described in their report as short-term memory) to immediate memory. MacVane, Butters, Montgomery and Farber[13] reported significant correlations between current quantity per occasion and performance on a verbal memory task employing the Brown-Peterson technique of distraction for periods of 15 and 30 seconds prior to recall. The correlation between quantity per occasion and recall after a 30 second delay was significant in both light and heavy drinkers. Waugh, Jackson, Fox, Hawke and Tuck[14] defined three groups of subjects based on daily alcohol consumption estimated with a quantity-frequency method, and reported significant group differences between subjects drinking greater than 80g/day and the two groups consuming less than 80g/day on the Rey Auditory Verbal Learning Test (RAVLT), but no significant differences between the subjects drinking up to 40g/day and those drinking between 41-80g/day.

Although these studies do not provide replications of any particular test result, they suggest that performance on complex verbal memory tasks, involving a delay or the introduction of interference, may be related to level of alcohol consumption. However, the level of alcohol consumption which may lead to impaired cognitive functioning is unclear. Parker et al[15] have recently suggested that the effects of level of alcohol consumption on cognitive functioning may only be manifest in subjects drinking at least three times per week.

The present experiment was designed to evaluate the relationship between level of alcohol consumption and verbal memory in social drinkers by recording the electrical activity of the brain while subjects memorised lists of words using either rote learning strategies or elaborative learning strategies. This task has been validated in a number of studies[16,17], and the results indicate that a positive component occurring between 700 and 1100 ms after stimulus presentation is consistently elicited when subjects engage in elaborative learning strategies and that the amplitude of this component predicts subsequent recall under elaborative learning strategies.

The recording of event-related potential data (ERPs) during information processing tasks has provided a valuable means for assessing subtle cognitive impairments and for identifying the nature of the deficits in other clinical populations[18,19]. Therefore, examination of the ERPs elicited during verbal memory tasks requiring complex integration of information may provide a more sensitive index of the subtle cognitive deficits resulting from moderate alcohol consumption suggested by previous research. Furthermore, ERPs provide a means of investigating the various stages of memory processing which cannot be identified in performance measures alone, and hence may indicate which stage of memory processing is disturbed in social drinkers.

METHODS

Subjects

Eighteen subjects participated in the experiment (14 males, 4 females; all right-handed). Subjects were excluded from taking part in the experiment if they had a history of seizures, severe head injury or extended periods of loss of consciousness, a personal or family history of psychiatric illness, if they were currently taking any psychoactive medication, or if they had ever sought treatment for drug or alcohol related problems. They were asked to refrain from consuming alcohol for 24 hours prior to the testing sessions, and were excluded from further testing if they failed to comply with this instruction. Subjects were excluded from the analysis if they had completed more than 16 years of education, to alleviate possible ceiling effects in the memory tasks.

Procedure

Subjects were tested on two occasions, approximately one week apart. In the first session, the experimental procedure was explained to the subject and written consent obtained. The preliminary screening instrument to obtain basic demographical data was administered, and the cognitive tests and drinking history tests were completed. The baseline and practice lists for the free-recall verbal memory experiment were also completed. In the second session, the electroencephalograph was recorded while subjects memorised the free-recall verbal memory lists. Each session lasted approximately two hours.

Drinking history questionnaires

The subjects were administered the Lifetime Drinking History Questionnaire[20] to obtain estimates of recent and lifetime quantity and frequency of alcohol consumption, the Family Tree Questionnaire[21] and the Michigan Alcoholism Screening Test (MAST)[22]. Subjects were excluded from the analysis if the scores on the MAST exceeded 14. The subjects were given a take-home diary and asked to record their level of alcohol consumption for the period between session 1 and 2.

Cognitive tests

Subjects completed a battery of tests selected on the basis of their ability to discriminate severely dependent problem drinkers from controls. The battery consisted of the following cognitive tests: National Adult Reading Test (NART) as an estimate of IQ; Rey Auditory Verbal Learning Test (RAVLT) and a Low Imageability Verbal Learning Test consisting of 15 words with a low imageability rating[23] but matched in frequency, word-length and number of syllables to words from the RAVLT, (the order of presentation of these two tests was counterbalanced across subjects); Block Design subtest from the Wechsler Adult Intelligence Scale (WAIS); Little Man test, (a mental rotation task involving visual presentation on a computer display of a picture of two men, each holding a drink in one hand. The orientation of each varied independently and the subject's task was to indicate whether the two men were holding the drink in the same hand); a verbal/visual recognition memory/temporal sequencing task[24] and a free-recall verbal memory task. The free-recall memory task involved visual presentation of ten 9-word lists with free-recall at the end of each list, followed by subjective report of strategy use. Subjects then completed a practice series of ten 9-word lists following instructions to utilise rote strategies and a practice series of ten 9-word lists following instructions to utilise elaborative strategies. In the second session, subjects were again instructed in the rote and elaborative learning strategies and presented with twenty 9-word lists for each type of learning strategy. The order of presentation of rote and elaborative learning strategies was counterbalanced across subjects.

Event-related potential recording

The electroencephalograph was recorded at F3, F4, P3 and P4 electrode sites using an electrode cap (Electro-Cap International) and referenced to the tip of the nose. Vertical eye movement was monitored with electrodes placed 2cm above and below the left eye. Horizontal eye movement was monitored with electrodes placed on the outer canthus of both eyes. The data was amplified using Neomedix NT114-A amplifiers with lower and upper frequency cutoffs of 0.016 and 50 Hz respectively (3dB down). The data were digitised at a rate of 6 ms per channel and stored on computer disk for subsequent averaging.

RESULTS

Drinking group classification

Subjects were classified into two groups (9 subjects per group) on the basis of reported average level of alcohol consumed per occasion, using the levels recommended by the National Health and Medical Research Council[25]. These levels were less than 4 standard drinks per occasion for males and less than 2 standard drinks per occasion for females in the 'light' drinking group, and greater than or equal to 4 standard drinks per occasion for males or greater than or equal to 2 standard drinks per occasion for females in the 'heavy' drinking group. To enable international comparison of standard drink units, the method recommended by Miller, Heather & Hall[26] has been adopted and these levels converted to volume of absolute ethanol. The equivalent cutoff points for the two groups are 50.7 ml absolute ethanol for males and 25.3 ml absolute ethanol for females. The estimated consumption was derived from the most recent phase of the lifetime drinking history questionnaire. The range of reported alcohol levels consumed per occasion in the present sample was zero to

126.7 ml, and the mean levels were 19.7 (s=14.3) and 85.9 (s=32.8) ml absolute ethanol for the light and heavy drinkers respectively. This difference was statistically significant (t=5.55, p<.001). Subjects in the heavy group reported drinking at their average level three to four times per week.

The heavy drinkers obtained significantly higher MAST scores than the light drinkers (F=7.51, p=.015). The mean MAST scores were 0.9 (s=1.1) and 5.9 (s=5.3) for the light and heavy groups respectively. MAST scores were significantly correlated with reported level of consumption in the present sample (r=.60, p<.01). Two of the subjects from the light group and four of the subjects from the heavy group reported a positive family history of alcohol related problems.

Demographic variables
The two groups did not differ in age or education (F=0.112, p=.742 and F=1.98, p=.178 respectively). The mean age of the light drinkers was 26.4 years (range 24-32) and of the heavy drinkers was 27.1 years (range 19-33). The mean education level attained was 15 years (range 12-17) and 13.9 years (range 12-17) for the light and heavy drinkers respectively. However, the groups did differ on estimated IQ as measured by the NART (t=3.78, p=.002), with the light drinkers obtaining higher scores than the heavy drinkers ($\bar{x}$=118, s=2.3 and $\bar{x}$=113, s=3.5 respectively). The range of scores obtained did not suggest that the NART was an inappropriate measure due to extremely high or low IQ subjects or to poor readers in either group[27]. The scores obtained by subjects in the light group ranged from 114 to 123 and for the heavy group the scores ranged from 108 to 118. Estimated IQ was significantly correlated with reported level of alcohol consumption in the present sample (r=-0.59, p=.01).

Cognitive tests
The mean levels of performance on all psychological tests for the two groups are presented in Table 1. There were no statistically significant differences between the groups on any of the psychological tests administered. However, the effect sizes typically reported on the psychological tests are small, and the absence of group effects in the present study may reflect low power due to the small sample sizes.

Analysis of free-recall behavioural data
The serial position data were analysed using BMDP-2V analysis of variance with condition (rote, elaborative) and position as repeated measures factors and group as a between subjects factor. Performance was higher with elaborative learning strategies than with rote learning strategies (F=36.72, p<.001). To evaluate primacy and recency effects (main effect of position, F=6.05, p<.001), multiple comparisons were carried out comparing each serial position with the adjacent serial position. These comparisons suggested that a marked primacy effect occurred for the first item presented (position 1 vs position 2; t=8.24, p<.001), and that a marginal recency effect was apparent for the last two items in the list (position 7 vs position 8; t=2.43, p=.026).

Table 1: Mean performance on psychological tests (and standard deviations) for light and heavy drinking groups.

TEST	LIGHT (Mean)	s.d.	HEAVY (Mean)	s.d.	F	p
Age (yrs)	26.4	3.1	27.1	5.3	0.11	.742
Education (yrs)	15.0	1.4	13.9	1.9	1.98	.178
NART (correct)	38.2	2.8	31.8	4.3	14.30	.002
RAVLT (Total Rec)	60.2	6.4	58.6	8.3	0.23	.639
Low Im (Total Rec)	50.0	11.8	47.3	10.0	0.27	.612
Block Design	41.3	9.0	40.0	8.6	0.10	.752
Verbal Rec % corr	81.2	13.6	73.6	13.6	1.41	.253
Verbal Temp % corr	80.2	14.4	72.2	24.2	0.73	.405
Visual Rec % corr	89.3	6.6	83.7	11.2	1.64	.219
Visual Temp % corr	84.9	12.0	77.8	14.6	1.28	.274
Rotation Hits (n)	25.6	2.4	26.2	1.3	0.54	.475
Rotation RT (ms)	3586	869	2894	673	3.56	.077
Natural Strat % rec	51.7	9.2	52.2	10.8	0.01	.913
Rote Prac % rec	46.2	12.4	46.1	8.0	0.00	.990
Elab Prac % rec	62.8	7.7	63.1	12.4	0.01	.947
Rote (S2) % rec	48.0	7.1	50.3	10.0	0.30	.593
Elab (S2) % rec	58.0	10.8	62.1	13.2	0.46	.510

The recency effects obtained are considerably smaller than those typically reported with free-recall of word lists presented visually[28,29]. Bousfeld, Whitmarsh & Esterton[30] reported marginal recency effects which they suggested was the result of presenting lists that did not exceed the immediate memory span. Other interpretations of their reduced recency effects have included the presentation of varied list lengths and the possible interpretation of the instructions by the subject for the requirement of serial recall[29]. The results presented by Bousfield et al suggest that subjects recalled items in serial order with list lengths of 6 items but the pattern of recall varied for the 10, 20 and 40 word lists. Recalling items other than the last few as the initial output items has been shown to markedly reduce the recency effect[28].

The present experiment employed fixed list lengths, although it is possible that the reduced recency effects observed may be due to the order in which subjects recalled the items. The order of recall was analysed by calculating the mean serial position for the first three items recalled. Analysis was restricted to the first three items recalled to ensure that an equal number of words contributed to each average. These data were analysed with a multivariate analysis of variance with condition (rote, elaborative) and output order (first, second, third) as repeated measures factors using SPSS-X. Both groups initially output items from the middle portion of the list (serial positions four/five). The light drinkers recalled the three items in serial order, whereas the heavy drinkers recalled the first two items in serial order, but the third was not (Wilks criterion: overall group by order interaction; $F=3.76$, $p=.048$; output item 2 vs output item 3; group by order interaction; $F=7.21$, $p=.016$).

The present experiment was employed to investigate the organisation and integration of the lists when subjects were instructed to utilise elaborative instructions. The overall performance data suggested that the heavy drinkers did follow the instructions as there was a significant increase in recall under elaborative strategies. However, the overall performance does not provide a means of evaluating the within-list organisation. Although attempts have been made to measure the subjective organisation imposed on random lists[31], these methods require repetition of the same list over trials. As this experiment presented each list once, an alternative procedure was required. The grouping of items within the serial position curves was examined by calculating the transition error probability (TEP) for each serial position using the method described by Bower[32]. The TEP is the conditional probability of recall of each item in the list, given recall of the preceding item, and distinct temporal groups are identified by an increase in adjacent TEPs. The size of groups formed over the list during elaborative strategies was analysed by comparing the number of words between the first and second peaks in the individual TEP curves. The heavy drinkers formed smaller groups than the light drinkers under elaborative learning strategies ($F=5.3$, $p=.035$), and the difference failed to reach statistical significance with rote learning strategies.

Analysis of ERP Data

The data were averaged separately for subsequently recalled and not recalled words from the plateau portion of the curve (positions 3 to 6). Averaged epochs encompassed an interval from 100 ms prestimulus to 1500 ms post-stimulus with a 20 ms baseline adjustment at stimulus onset. The grand mean waveforms comparing recalled and not recalled words under rote and elaborative instructions for the two groups are presented in Figures 1 and 2. The words have elicited clearly defined peaks over the parietal scalp sites (P3 and P4) between 100 and 300ms post-stimulus reflecting sensory registration of the stimulus. These peaks are labelled according to their polarity as P1, N1 and P2 reflecting the first positive deflection, the first negative deflection and the second positive deflection. The pattern and scalp topography of the peaks is modality specific, and the observed peaks resemble those typically elicited with visual stimuli. The waveforms also exhibit a later negativity which will be labelled according to its polarity and peak latency as the N400 component. This negativity is apparent at both frontal and parietal scalp sites.

Figure 1. Grand mean ERP waveforms elicited during the free-recall memory task when rote learning strategies were utilised comparing recalled and not recalled items.

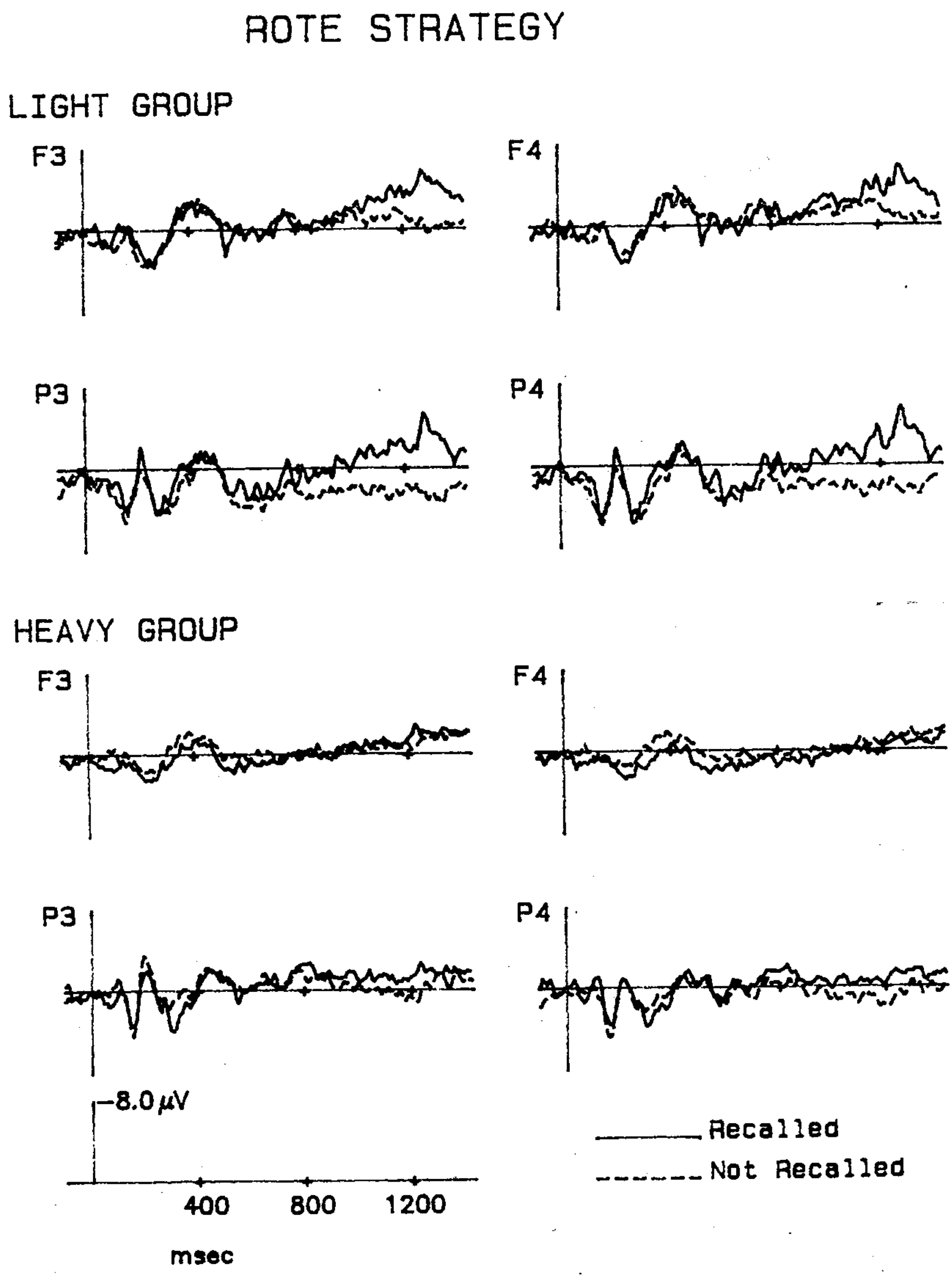
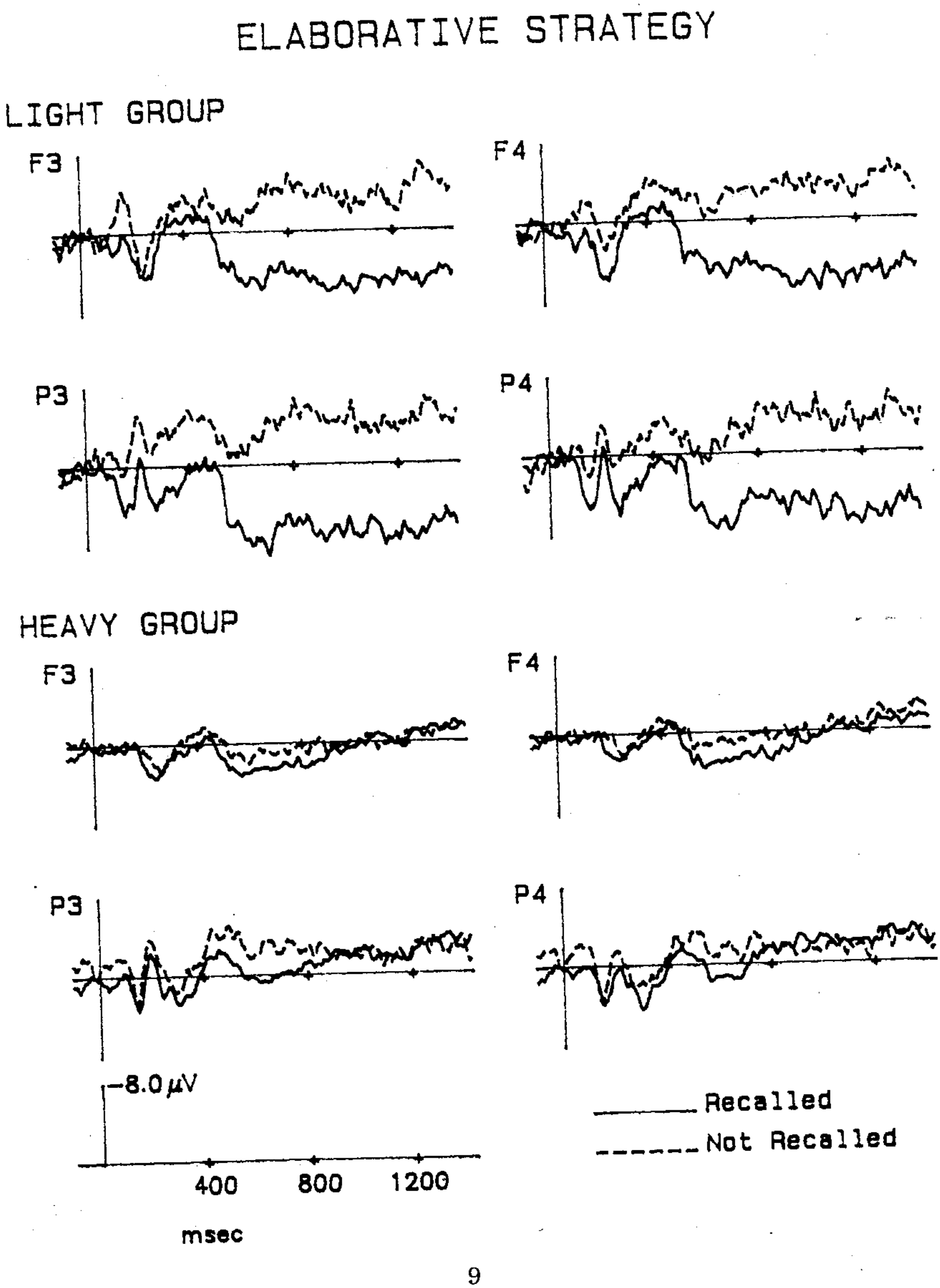


Figure 2. Grand mean ERP waveforms elicited during the free-recall memory task when elaborative learning strategies were utilised comparing recalled and not recalled items.



Under elaborative instructions, the subsequently recalled words appear to have elicited a broadly distributed positivity in the light drinking group although this effect is not apparent in the heavy drinking group. The difference between the ERPs elicited by subsequently recalled and not recalled words will be referred to as the ERP memory effect in this paper. The ERP memory effect commences as early as 100ms and continues to the end of the epoch. On the basis of previous papers and from visual inspection of waveforms, the mean amplitudes were measured over the following epochs: -100 ms to stimulus onset, 100-300, 300-500, 500-700 and 700-1100 ms. The data were analysed using BMDP-2V with condition (rote, elaborative), memory (recalled, not recalled), electrode (frontal, parietal) and hemisphere (left, right) as repeated measures factors and with group (light, heavy) as a between subjects factor. Multiple comparisons were carried out using separate error estimates for each contrast and the alpha level adjusted for the number of comparisons. Significant interactions involving the between subjects factor were further investigated by carrying out two types of multiple comparisons comparing the within subjects effects for the two groups separately, and comparing the two groups at each level of the within subjects factor.

<u>Prestimulus effects</u>

There were no significant prestimulus effects identified in the 100 ms preceding stimulus onset.

<u>100-300 ms</u>

The N1 peak was larger over the left hemisphere than over the right hemisphere at parietal scalp sites (main effect of hemisphere, $F=6.08$, $p=.025$; electrode x hemisphere interaction, $F=6.12$, $p=.025$).

<u>300-500 ms</u>

Subsequently recalled words elicited a larger positivity than not recalled words over the 300-500 ms epoch (main effect of memory, $F=8.16$, $p=.011$).

<u>500-700 ms</u>

With elaborative learning strategies, subsequently recalled words elicited a larger positivity than not recalled words between 500-700 ms (main effect of memory, $F=19.45$, $p=.001$; condition x memory interaction, $F=7.83$, $p=.013$).

<u>700-1100 ms</u>

A larger positivity was elicited for subsequently recalled words than for not recalled words under conditions of elaboration in the light drinkers. This ERP memory effect was not apparent in the heavy drinkers (main effect of memory, $F=9.53$, $p=.007$; condition x memory interaction, $F=8.28$, $p=.011$; memory x group interaction, $F=7.74$, $p=.013$; condition x memory x group interaction $F=5.37$, $p=.034$).

It is possible that the ERP effects demonstrated in the present study reflect differences which are related to level of alcohol consumption or to other variables on which the two groups differed. The groups differed in the present study on MAST and NART scores (and possibly on other factors which have not been measured). It is conceivable that the observed effects could be related to both estimated IQ and reported problems associated with excessive alcohol use in the past. Correlation coefficients were calculated between the amplitude of the ERP memory effect and reported drinking levels, scores on the MAST and

NART scores in the total sample. The correlations obtained are presented in Table 2. These results suggest that the ERP memory effect elicited during elaborative learning strategies was significantly correlated with both reported drinking levels and with NART scores, but uncorrelated with MAST scores. The correlations between the ERP memory effect elicited under rote learning strategies and level of alcohol consumption were non-significant. Partial correlations between the ERP memory effect elicited during elaborative learning strategies and average drinking level after controlling for estimated IQ are presented in Table 3. These results suggest that the relationship between average level of alcohol consumption and the ERP memory effect elicited during elaborative learning strategies was significant after controlling for the effect of estimated IQ, primarily over the parietal electrode sites.

Table 2. Pearson correlations between reported level of alcohol consumption, MAST scores, NART scores and the amplitude of the ERP memory effect between 700-1100ms at the four electrode sites.

	Rote				Elab			
Electrode	F3	F4	P3	P4	F3	F4	P3	P4
Mls ethanol	.29	.14	.18	.14	-.54*	-.53*	-.61**	-.67**
MAST	-.20	-.25	-.19	-.23	-.07	-.04	-.20	-.21
NART	-.40	-.25	-.54*	-.54**	.40	.39	.56**	.55*

* $p<0.05$
** $p<.01$

Table 3. Partial correlation coefficients between average level of alcohol consumption and the ERP memory effect between 700 and 1100 ms after controlling for estimated IQ.

	Rote				Elab			
Electrode	F3	F4	P3	P4	F3	F4	P3	P4
Mls ethanol	.07	-.01	-.21	-.26	-.41	-.40	-.42*	-.51*

* $p<0.05$

DISCUSSION

The major findings from the present study suggest that light and heavy drinkers differed significantly in the amount of information organised and integrated when instructed to utilise elaborative learning strategies. This conclusion is supported by the absence of the late (700-1100ms) ERP memory effect in the heavy drinking group and by an analysis of the number of items associated during the elaborative strategies. However, the differences between the groups were not evident in the overall performance measures (such as percentage of items recalled), highlighting the importance of investigating more sensitive behavioural indices of memory processes in addition to obtaining overall measures of performance. The recording of event-related potentials while subjects perform memory tasks provides an excellent opportunity to observe the underlying processes which may not be apparent from overall performance measures. Furthermore, the amplitude of the late ERP memory effect was significantly correlated with the average level of alcohol consumed after statistically controlling for estimated IQ. Subjects were required to abstain from consuming alcohol for 24 hours prior to the experimental sessions and the results therefore are not the result of acute intoxication.

The two groups did not differ significantly in the ERP memory effects occurring between 300 and 700 ms. It is possible that these memory effects consist of a number of different components. The ERP memory effect over the 300-500 ms epoch was elicited during both rote and elaborative learning strategies. This difference may reflect an increased positivity for the recalled words or an increased negativity for the not recalled words. N400 components have been examined in a variety of paradigms, and the different tasks reporting negativities over the 300-500 ms latency range probably reflect a number of components. Dissociations between different components have been identified by determining that they have differing scalp topographies. Neville, Kutas, Chesney and Schmidt[33] report an increased positivity for subsequently recognised words over this epoch for items which were semantically primed by a phrase, but with no evidence of such a relationship in words which were unrelated to the priming phrase. In addition, the amplitude of the memory effect was largest over the parietal and temporal left hemisphere whereas the effect of semantic priming was largest over the parietal right hemisphere. Unfortunately, possibly because of the limited number of sites recorded, there are no significant electrode or hemisphere effects for the memory effect in the present study, and hence it is difficult to identify it on the basis of scalp topography.

The ERP memory effect occurring between 500-700 ms resembles the later frontal positive slow wave observed in this and other experiments as it was apparent when subjects utilised elaborative learning strategies. The groups did not differ on the amplitude over this region, suggesting that both groups were elaborating to some extent in the present experiment.

Over the 700-1100 ms epoch the ERP memory effect was elicited under elaborative instructions. The heavy drinkers showed no evidence of this late

ERP memory effect, suggesting that they did not integrate and organise the items to the same extent as the light drinkers when instructed to utilise the elaborative strategies. A number of results from the analyses suggest that the subjects obeyed the instructions to elaborate: they indicated for each list whether they had utilised the appropriate strategy, there was a significant improvement in performance between the rote and elaborative learning strategies, and there were no significant group differences in the ERP memory effects between 300 and 700 ms. However, the results from this epoch, suggesting that the heavy drinkers did not elaborate to the same extent as the light drinkers, are consistent with the behavioural data from the transition error probability curves as the size of the groups formed under elaborative strategies was smaller for the heavy drinkers than for the light drinkers. Therefore, it is somewhat surprising that their performance under elaborative conditions was not impaired in this case. One possibility is that with only nine words in the list, the memory demands of the task were not sufficient for the small inter-item group sizes to affect overall memory performance. The serial position curves also suggest that a sequence of nine meaningful stimuli did not exceed the immediate memory span, and may therefore not be sufficiently demanding. If the present ERP and TEP data reflect an inability to form larger units, it is likely that performance may deteriorate with longer word lists. It would be necessary to increase the list length to evaluate this hypothesis, and it would also be possible to obtain subjective reports of group sizes to evaluate whether heavy drinkers formed less extensive inter-item associations during the encoding of the word lists, or whether the group sizes during encoding were similar, but with loss of items within an associated unit during the retrieval phase.

The magnitude of the correlations between the ERP memory effect and level of alcohol consumption were considerable. The partial correlations between average drinking level and the magnitude of the ERP memory effect after controlling for IQ suggest that the memory effect at parietal sites is more closely related to level of alcohol consumption than the effect at frontal sites. It may be necessary to investigate the type of elaborative strategy used by the subjects in more detail to understand the scalp topography of the memory effects on ERPs. Farah and Peronnet[34] reported that generation of the image of an object elicited an occipito-parietal positivity. Therefore, the scalp topography of the memory effect is likely to be different in subjects employing elaborative strategies involving the integration of words into a visual image or picture compared with subjects who form sentences or stories from the words. In future experiments we will be obtaining subjective reports on the type of elaborative strategies used.

Although these results suggest a relationship between reported level of alcohol consumption and ERP indices of memory processing, they do not indicate that alcohol necessarily causes this effect. However, a number of factors which have been suggested to influence the reported relationship between alcohol consumption and cognitive functioning in moderate drinkers have been investigated in the present study. The results were statistically significant even after controlling for estimated IQ, and therefore the observed differences are unlikely to reflect differences in innate ability per se. However, as in many of the studies in this area, there were significant differences between the groups on estimated IQ emphasising the need to control for this variable in future studies.

The present study has utilised the drinking measure which has most frequently been reported to be related to cognitive functioning in the literature, namely recent quantity per occasion. It does not provide a direct test of the competing hypotheses concerning the mechanisms responsible for the relationship for example, whether the relationships observed reflect a hangover effect, a long-term neurotoxic effect of alcohol on the brain, withdrawal reactions, or whether they are related to some extraneous variable such as stress or genetic predisposition. However, the results from this study suggest that the recording of event-related potentials during complex verbal learning tasks may provide a sensitive index of memory processes which are related to the effects of alcohol in a direct or indirect way.

One factor which has not been examined in the present study and which could be potentially relevant is the effect of anxiety. A relationship between stress or anxiety and the level of cognitive functioning in social drinkers has been observed in a number of studies[10,35]. High levels of anxiety have also been reported to reduce the storage and processing capacity of working memory[36,37]. It is possible that highly anxious subjects may drink more heavily than less anxious subjects in an attempt to alleviate their anxiety or alternatively that subjects drinking at heavier levels would be more anxious in an experimental situation evaluating the effects of alcohol consumption on cognitive functioning. We will include a measure of state anxiety to evaluate this hypothesis in future.

The tasks used are related to the reported impairments following excessive alcohol use, namely organisation and integration of information. The results from the present experiment indicate that measuring the event-related potentials elicited during tasks which are relevant to the hypothesised cognitive disturbances associated with alcohol consumption may provide further information on the nature of the impairment. This, in turn, may lead to the development of more sensitive behavioural indices of the effects of alcohol on memory. In addition, ERPs may also provide a sensitive index of subtle dysfunction, which could contribute to the early identification of changes to cognitive functioning and enable early intervention in subjects at risk of developing impairments.

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